Synoptic-Scale Weather Disturbances that Influence Fire Climate in Southeast Asia During the Normally Dry Period . . . final report

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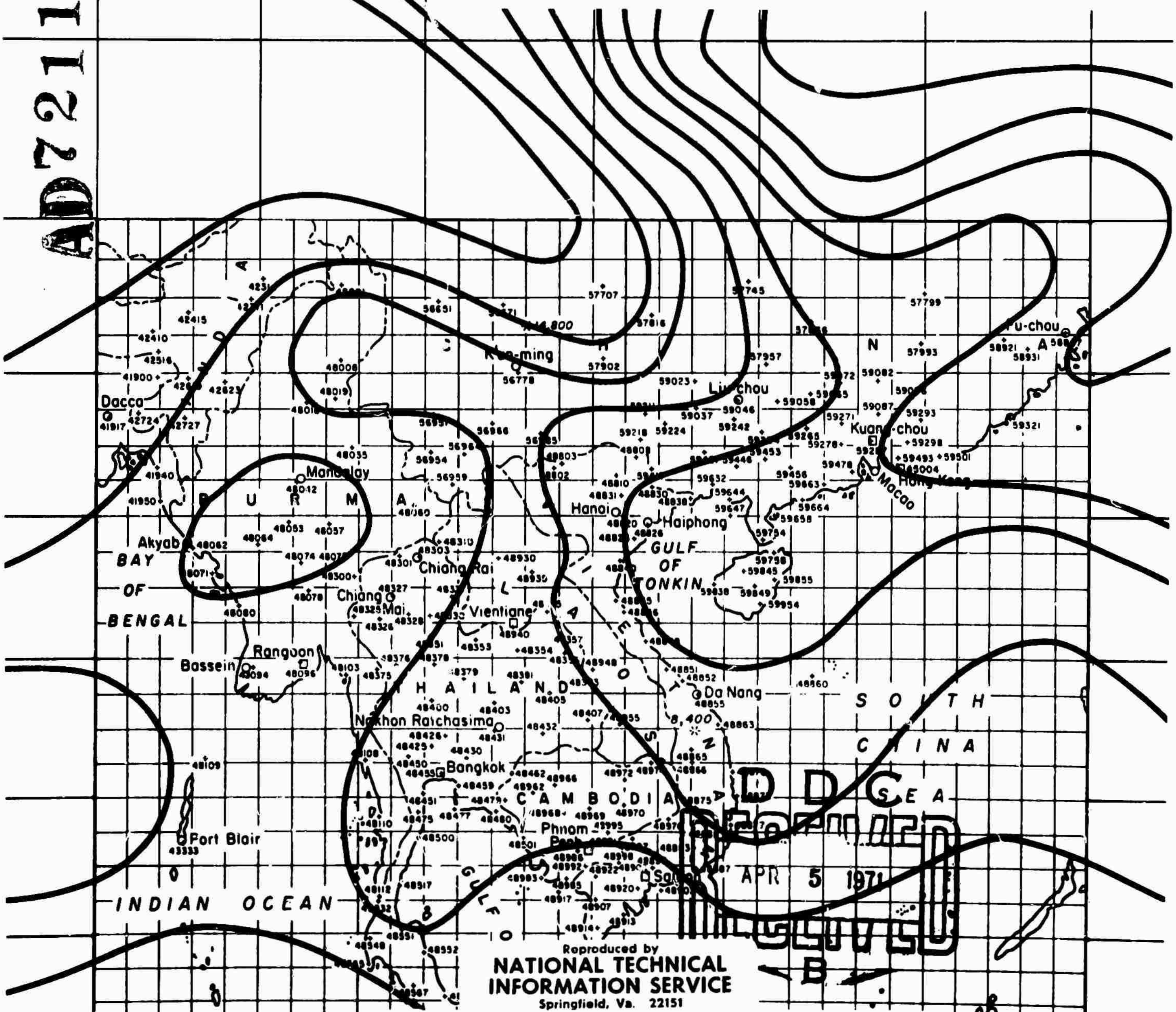

PACIFIC SOUTHWEST Forest and Range Experiment Station

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
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Final Report

by

Morris H. McCutchan

and

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Pacific Southwest Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture
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ABSTRACT

Fire climate in Southeast Asia is affected by two major factors, rainfall and cloud cover. By "fire climate" we mean the climate that affects the inception and behavior of wildfire. In our study of the fire climate in Southeast Asia we investigated, when, for how long and by what mechanism the normally dry period (November through April) is interrupted by widespread rain and clouds.

We found five types of synoptic-scale weather disturbances usually responsible for extensive rainfall over Southeast Asia during the dry period. We give case histories of general rain that were caused by these five types of disturbances: (1) 30 November 1962--tropical cyclones and easterly waves; (2) 21-23 March 1963--troughs in the westerlies; (3) 24 and 25 November 1962--superposition of trough in the westerlies on easterly waves; (4) 29 March 1963--surges of the northeast monsoon; and (5) 7-9 March 1963--tropical troughs.

CONTENTS

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We thank Robert S. Helfman, who did the computer programing with assistance from George T. Flatman and Brian W. Bauske. We also thank Mrs. Louella Braatz, who typed the manuscript, and Mrs. Ideka Kerek, Miss Audrey Kursinski, and Miss Joyce Ridgle, who prepared the illustrations.

Fire climate is affected by temperature, humidity, wind speed, precipitation, and cloud cover. In Southeast Asia (SEA), the two major factors are rainfall and cloud cover. The dry period there generally extends from November through April and the wet period from May through October (Environmental Technical Applications Center 1967).

In 1968, the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, investigated when, for how long, and by what mechanism this normally dry period in Southeast Asia is interrupted by rain and clouds. The study was sponsored by the Advanced Research Projects Agency, U.S. Department of Defense, under ARPA Order No. 818.

To find the answers, we determined the rainy periods and associated these periods with the synoptic-scale weather disturbances responsible by using the techniques of synoptic climatology developed by Jacobs (1946). In the process, we investigated the origins, frequency, persistence, dissipation, dynamics, kinematics, and associated fire climate of these synoptic-scale disturbances. This scale measures the high and low pressure systems of the lower troposphere with wave length of 1,000 to 2,500 kilometers.

In a preliminary report, McCutchan and Helfman (1969) described the climatological data and map sources used for the study, the computer programs used to organize and display the data, and provided a detailed analysis of one synoptic-scale weather disturbance responsible for general rain in Southeast Asia--the tropical trough.

In this final report, we provide case histories as examples of each of the five types of synoptic-scale disturbances that are usually responsible for rain in Southeast Asia during the normally dry period (November through April). The five types are: (1) tropical cyclones and easterly waves; (2) troughs in the westerlies; (3) superposition of troughs in the westerlies on easterly waves; (4) surges of the northeast monsoon; and (5) tropical troughs.

EARLIER STUDIES

Some research has been done on synoptic-scale weather disturbances affecting SEA during the dry season, but most researchers have concentrated on the rainy period. Ramage (1955) was one of the few who studied the dry period. He discovered the "tropical trough" to be the major rain producer during this normally dry period. He gave this name to a cold-core disturbance that appears over southern India at or above 30,000 feet and moves eastward into Burma, Thailand, and Indochina. Ramage mentioned many unknowns about the trough. We found no evidence in the literature of further research until McCutchan and Helfman (1969) reported the trough responsible for the general rain in SEA on 7-9 March 1963.

Easterly waves and tropical cyclones are also synoptic-scale weather disturbances that move through the SEA area during the dry season. Much research has been done on easterly waves and tropical cyclones in the Atlantic and Pacific Oceans; for examples, by Dunn (1940) and, more recently, by Sadler (1963) and Merritt (1964), who used weather-satellite photographs. Easterly waves and tropical cyclones may not produce significant amounts of rain or clouds by themselves during the dry period, but Riehl and Shafer (1944) showed that superposition of a trough in the westerlies on an easterly wave often results in mutual intensification. Ramage (1952) and Ranganathan and Soundararajan (1965) found that this superposition can produce general rain and clouds in SEA during this period.

Other research in SEA during the dry period has been concerned with northeast monsoon surges--winter surge of northeast wind, which develops behind a cold front that is pushed south into Southeast Asia by the anticyclone over Siberia (Thompson 1951; Ramage 1960); crachin--a period of light rain, low stratus clouds, and bad visibility usually occurring between late January and early April and persisting for several days (Ramage 1954); the sub-tropical jet stream (Yeh 1950); the West China trough (Ramage 1960); and the general circulation (Thompson 1951; Mayhew 1965).

METHODS

Data on daily rainfall and total cloud cover at 1300 L.s.t. for about 200 individual weather reporting stations (fig. 1) and rawinsonde and radiosonde data for 31 upper-air stations were used in this report (fig. 2). All data were for the 6 months November through April for each year starting in 1959 and ending in 1964.

The University of California, Riverside IBM 360/50 computer and Cal-Comp plotter were used to produce plotted daily maps of rainfall and cloud amount, vertical time cross-sections, vertical space cross-sections, upper-air charts, and Skew T, Log P diagrams (Air Weather Service 1969) for the upper-air stations. The rainfall data were hand analyzed to show areal extent of ≥ 0.1 inch of rain per day. Likewise the cloud data were analyzed to show areal extent of clear, scattered, broken, and overcast cloud conditions. Areas of more than 20,000 square miles where ≥ 0.1 inch of rain per day fell, along with a broken or overcast cloud condition, were considered areas of general rain.

Maps analyzed by the Thailand Meteorological Department for surface, 850 mb., 700 mb., 500 mb., 300 mb., and 200 mb. for

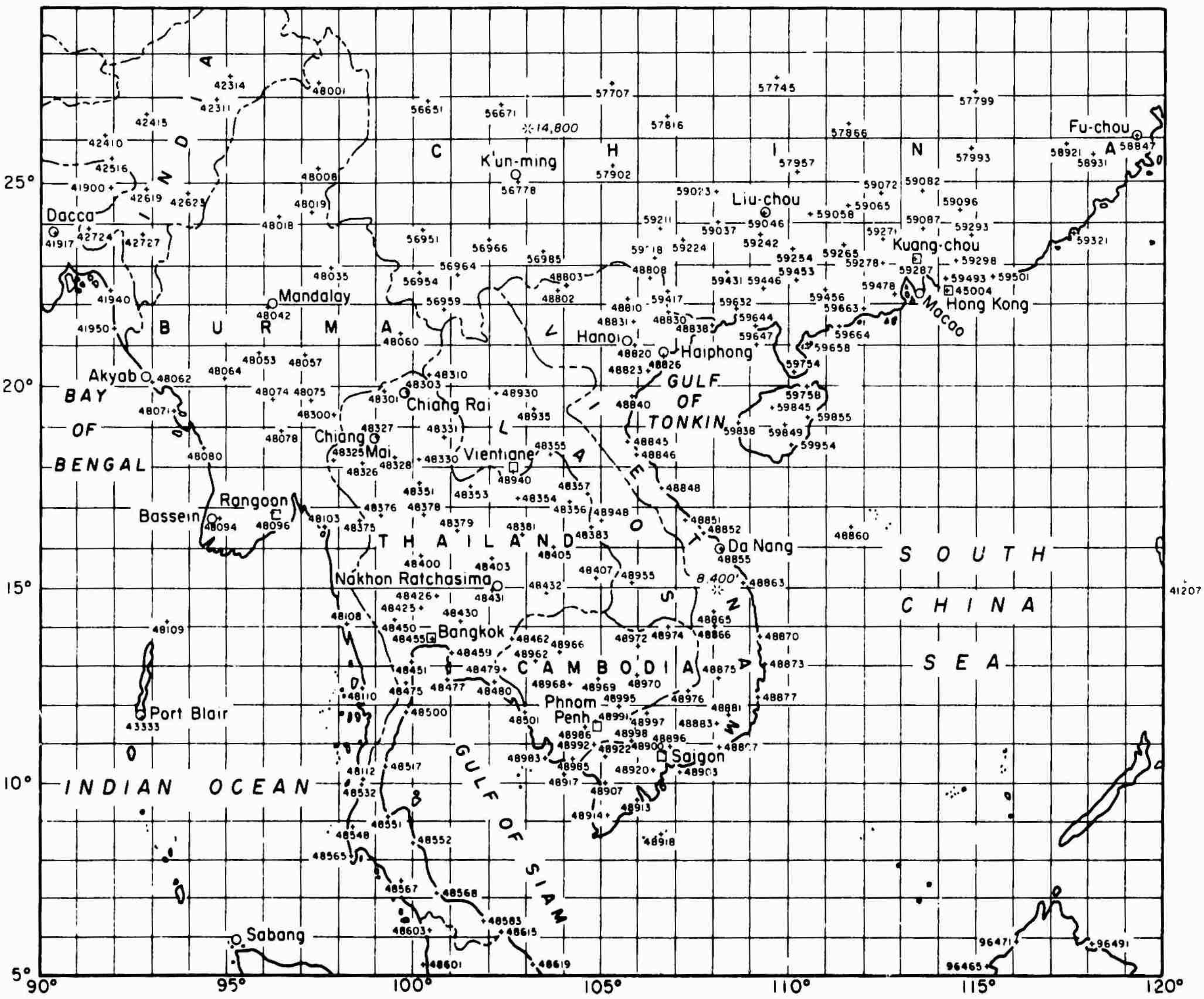

Figure 1.--Locator chart for data on precipitation and cloud.

January through April 1963, surface and upper-air maps for 1963 and 1964 analyzed at the Indian Meteorological Centre, surface and 300 mb. charts analyzed by the USAF Air Weather Service at Guam, and locally analyzed upper-air charts along with vertical time cross-sections, vertical space cross-sections, and Skew T, Log P diagrams, were used in the study.

Since analyzed maps were only available for November 1962 through April 1964, the synoptic-scale weather disturbances were determined for periods of general rain during this period only.

After the synoptic-scale disturbances responsible for these general rain and cloud conditions were determined, we used surface and upper-air charts, vertical time cross-sections, vertical space cross-sections, and Skew T, Log P diagrams to study and determine the origin, movement, dissipation, dynamics, kinematics, and associated fire climate of these disturbances.

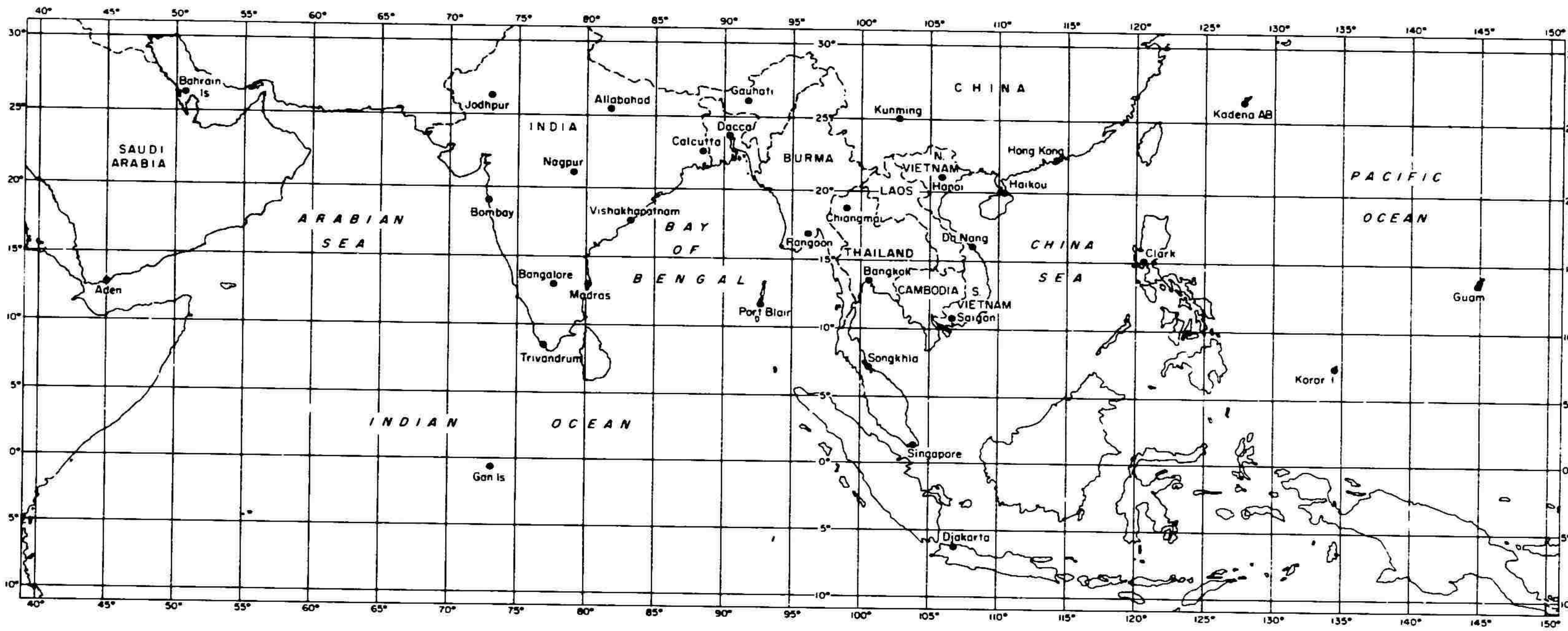

Figure 2.--Locator chart for rawinsonde data.

ANALYSIS

To determine the areas of general rain, we analyzed the maps showing 24-hour precipitation and total cloud cover at 0600 G.m.t. (1300 local time). When a period of general rain was determined, the vertical time cross-sections, vertical space cross-sections, and Skew T, Log P diagrams for the period were plotted and analyzed.

PRECIPITATION AND CLOUD COVER

The precipitation and cloud cover maps were analyzed for ≥ 0.1 inch of rainfall per day and for overcast, broken, scattered, and clear total cloud amounts. In the cloud-cover analysis, the cloud features described by Beran and Merritt (1967) were used as guidelines.

VERTICAL TIME CROSS-SECTION

The vertical time cross-section computer plotting sequence followed that recommended by Reiter (1963) and Saucier (1955). The data are displayed in the same manner as a vertical space cross-section. Thus, the troughs and ridges become evident from the veering and backing of the wind. The analyses of the cross-sections included the 24-hour height change for every 25 meters and the 24-hour temperature change for every 2°C. In addition, the dew-point depression was analyzed for > 10°C. and < 5°C. The areas with > 10°C. spread are dry areas and, as reported by Saucier (1955), the moist areas, i.e., < 5°C. spread, are not to be taken wholly as cloud patterns. Clouds may not exist in all the moist areas. On the other hand, cirrus may occur outside these areas. (Care must be taken when interpreting the temperature and moisture analysis below 1000 mb. because the height-pressure scale from 1000 mb. down to the surface is not the same as above 1000 mb. The height scale below 1000 mb. was expanded to facilitate plotting the surface data.)

VERTICAL SPACE CROSS-SECTION

Vertical space cross-sections were computer plotted along two axes: east-west and north-south.

The east-west cross-sections were analyzed for "D" values for every 25 meters, potential temperatures for every 5°K., and dew-point depression for > 10°C. and < 5°C. as in the case of vertical time cross-section. The "D" value is the observed height minus the height of the tropical atmosphere given by Fehlner et al. (1958). The potential temperature is given by

$$\theta = T(1000/p)^{2/7} \qquad (1)$$

in which T is the observed temperature in degrees Kelvin and p is the pressure of the level in millibars.

The north-south vertical space cross-sections were analyzed in two parts. In one part, the analysis is the same as the east-west type in which the analysis includes "D" values, potential temperature, and dewpoint depression. In the other part, however, the east-west wind component was analyzed for every 10 knots and the temperatures for every 5°C. A negative wind component indicates an east wind and a positive, a west wind. (Here again, care must be taken with the analysis below 1000 mb. because of the expanded scale.)

SKEW T, LOG P DIAGRAM

The Skew T, Log P diagrams were all analyzed for Showalter Index, and, if maximum temperatures were available, they were also analyzed for the "Lifted Index" (Galway 1956). The Lifted Index is similar to the Showalter Index, but Beran and Merritt (1967) claim that the Lifted Index is a more representative determination of low-level moisture and temperature values--an important consideration in the tropics. The Lifted Index was evaluated by first determining the mean mixing ratio in the lowest 3,000 feet by the equal-area method. Then the mean potential temperature in the lowest 3,000 feet at the time of convection was determined by using the maximum surface temperature for the day at the station and assuming a dry-adiabatic lapse rate through the lowest 3,000 feet. The lifting condensation level (LCL)--level at which a parcel of moist air lifted dry adiabatically becomes saturated--was located at the intersection of the mean mixing ratio and the mean potential temperature. The saturation adiabat through the LCL was extended to the 500 mb. level and the temperature at the intersection was determined. The Lifted Index, defined as the observed 500 mb. temperature minus the computed temperature, was computed.

UPPER-AIR CHARTS

Most of the upper-air charts used in the paper were analyzed either by the Thailand Meteorological Department, Indian Meteorological Centre, or the USAF Air Weather Service. No analyzed maps, however, were available for November and December 1962 that covered Southeast Asia and India. Consequently, we analyzed our own upper-air charts for these months from computer-plotted data.

Riehl (1954) recommends streamline analyses rather than contour analyses because of the large spacing between stations and the errors that upper-air soundings are subject to in the tropics. These errors may not be great, but are important because they can easily equal the magnitude of the synoptic variations.

The streamlines were drawn by using the isogon method as described by Saucier (1955). We did not include isotach analyses in this report because we were interested primarily in the wind flow patterns to detect troughs, ridges, cyclones, and anticyclones.

RESULTS

PERIODS OF GENERAL RAIN

Daily precipitation and cloud cover maps for the 6 months, November through April, for each year starting in 1959 and ending in 1964 were analyzed. Periods of general rain were determined for land areas within the area 6°N. to 24°N. and 92°E. to 110°E. General rain was considered to have occurred if ≥ 0.1 inch of rain per day occurred along with broken or overcast cloud condition over an area more than 20,000 square miles.

January was the driest month with only eight general rain days in the 5 years (table 1). No rain days at all occurred in January 1963 and 1964. December and February were also quite dry. The wettest months were November with 56 general rain days and April with 55 rain days for the 5-year period. November also had the longest periods of rain with a 17-day period in 1960 and a 11-day period in 1963.

Each analyzed map of general rain for those dates listed in table 1 were superimposed on the base map with 1-degree square references. The total number of days, by month, during the 5-year period that general rain fell within each 1-degree square was determined (figs. 3-8). Areas located along the coastline may be slightly misrepresentative as the analyses were based on data over land areas only. To further identify general rainfall occurrence, 10 random squares were graphed by using the year and number of days with rain ≥ 0.1 inch. These figures not only show which areas had the greatest number of general rain days, but show the variation, by year.

For example, the rainfall analyses for November (fig. 3) indicates that the most days of general rain occurred in southern South Vietnam and Cambodia, and the least number in northern Thailand and eastern Burma. (The number of rain days in northeastern Laos shown in figs. 3-8 are not representative because of lack of reporting stations.) Another maximum area of rain is north of Hanoi in southern China, but this area shows a high number of days on all months. This same geographical distribution of rain days for November is represented to a lesser degree in December (fig. 4). A significant drop in total rain days between the 2 months, however, is evident. January was even drier than December during these 5 years, with no 1-degree area having more than 4 days of general rain (fig. 5). Most of the highland area of Thailand and Laos had no rain days during the month.

The map for February indicates that total moisture in SEA increased over the previous month and that this moisture was somewhat more evenly distributed, except that most of Burma had no rain days at all (fig. 6). March and April have similar rain-day patterns (figs. 7,8). Although April was generally much wetter than March, areas of greatest rainfall during these 2 months are in northeast Thailand and, again, around Hanoi. Areas of dissimilarity between March and April are mostly south of Danang, where there were fewer rain days in March than in April.

Although April and November have about the same number of total rain days, rain days in April are more evenly distributed throughout SEA than those in November. Most of the high rain days in November were concentrated in the south--especially around the Saigon-Phnom Penh area.

Most of the high rain days in November occurred in 1960 (fig. 3), whereas the high occurrences which are evident in April reached a peak in 1962 (fig. 8). The graphs for all months and table 1 show that the period November 1962-April 1963 was the driest in the 5 years.

Table 1—Periods of general rain for land areas in Southeast Asia[1/]

MONTH/YEAR	DATES OF GENERAL RAIN	RUNS OF GENERAL RAIN DAYS 1	2	3	4	5	6	7	8	9	10	>10	TOTAL RAIN DAYS PER MONTH
November 1959	3-5, 7, 10, 20, 24-25	3	1	1									9
December 1959	11-14, 23-25			1	1								7
January 1960	21, 27-29	1		1									4
February 1960	2-3, 27-29		1	1									5
March 1960	1-6, 28-29		1				1						8
April 1960	2, 9-10, 15-16, 18, 21	3	2										7
November 1960	9, 14-30	1										1	18
December 1960	1-2		1										2
January 1961	5-6		1										2
February 1961	5, 18-19, 21, 28	3	1										5
March 1961	3, 7-11, 13-15, 17, 28-31	2		1	1	1							14
April 1961	6, 9-12, 15-20, 26-27, 29	2	1		1		1						14
November 1961	4-5, 9, 17, 21-24	2	1		1								8
December 1961	15, 23-24, [illegible], 1	3	1										5
January 1962	1, 17	2											2
February 1962	27-28		1										2
March 1962	2, 11, 16, 24-25, 29	4	1										6
April 1962	4, 10, 12-17, 19-22, 24, 26-30	3			1	1	1						18
November 1962	1-5, 24-25, 30	1	1			1							8
December 1962	13	1											1
January 1963													0
February 1963	12	1											1
March 1963	7-9, 12-13, 15, 21-23, 25, 29	3	1	2									11
April 1963	4, 8, 28-29	2	1										4
November 1963	1-11, 24, 26-27	1	1									1	14
December 1963	4, 11	2											2
January 1964													0
February 1964	21	1											1
March 1964	9, 25, 29-31	2		1									5
April 1964	1-2, 8, 12, 16, 18, 21-23, 25, 29-30	5	2	1									12

1/ General rain occurred if ≥ 0.1 inch of rain per day occurred along with broken or overcast cloud condition over an area more than 20,000 square miles, for land areas only within the area 6° N. to 24° N. and 92° E. to 110° E.

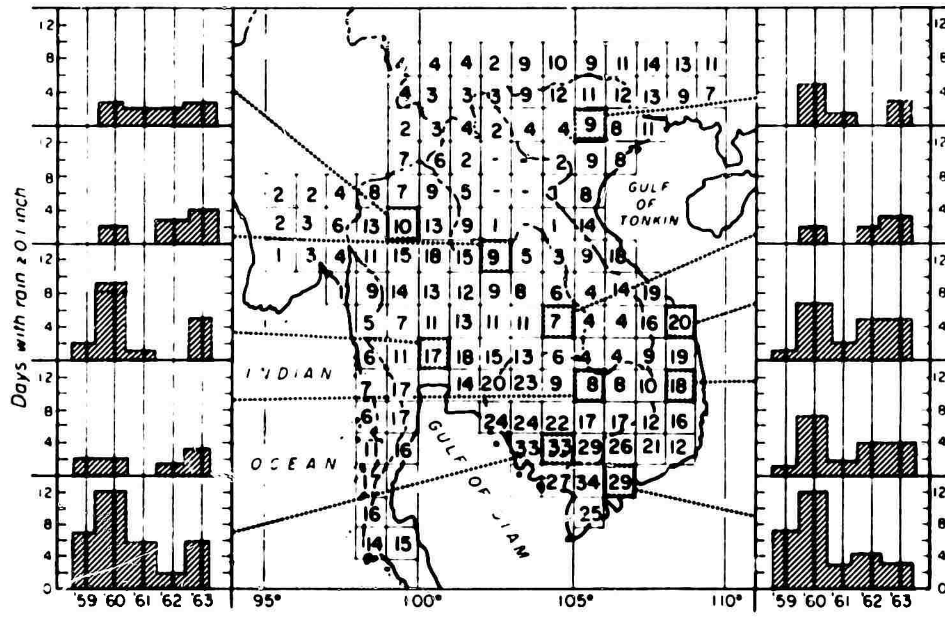

Figure 3.--Total number of days in November, during a 5-year period, general rain fell within each 1-degree square. Histograms show the number of days of general rain, by year, for 10 random squares.

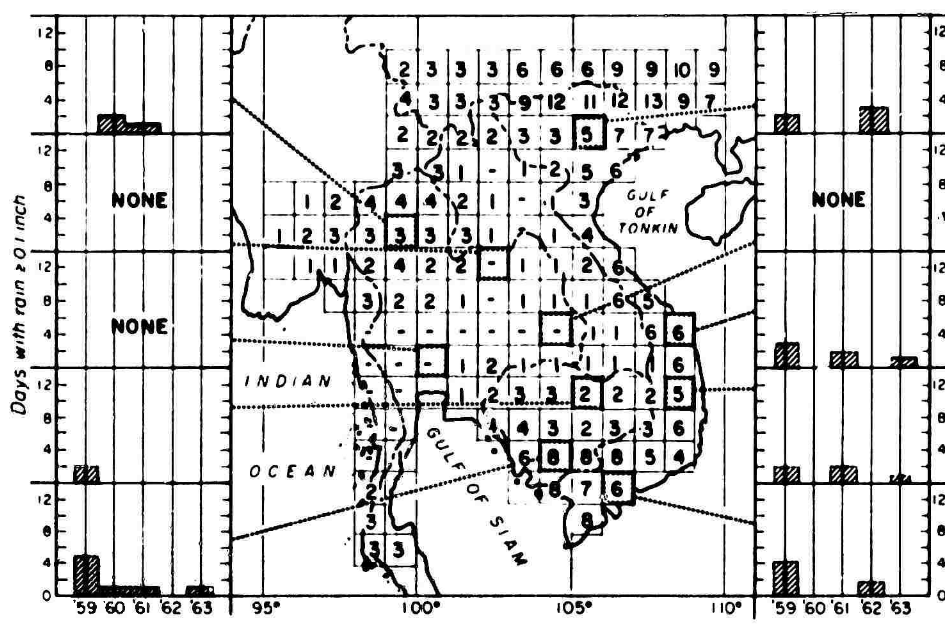

Figure 4.--Total number of days in December, during a 5-year period, general rain fell within each 1-degree square. Histograms show the number of days of general rain, by year, for 10 random squares.

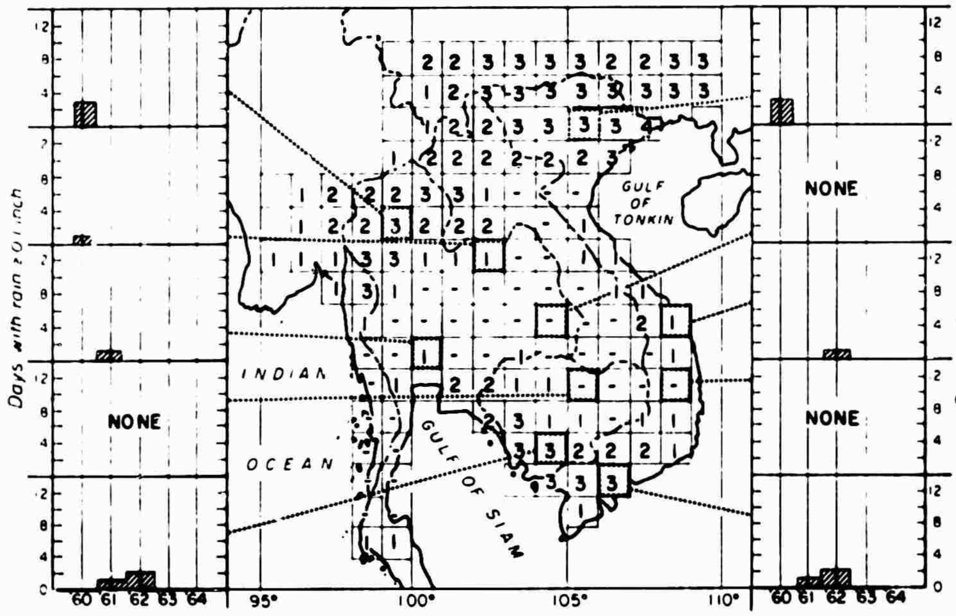

Figure 5.--Total number of days in January, during a 5-year period, general rain fell within each 1-degree square. Histograms show the number of days of general rain, by year, for 10 random squares.

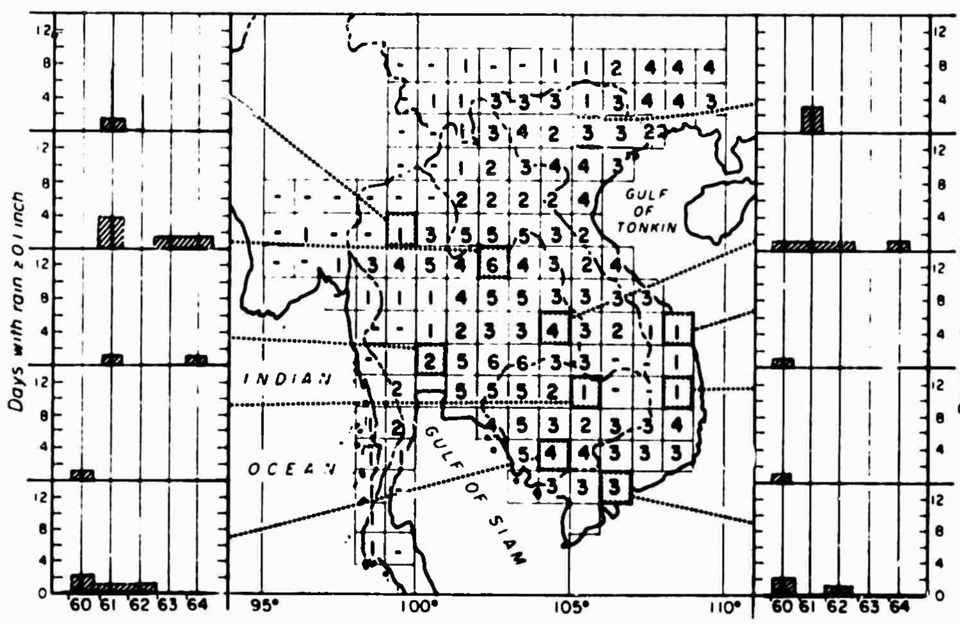

Figure 6.--Total number of days in February, during a 5-year period, general rain fell within each 1-degree square. Histograms show the number of days of general rain, by year, for 10 random squares.

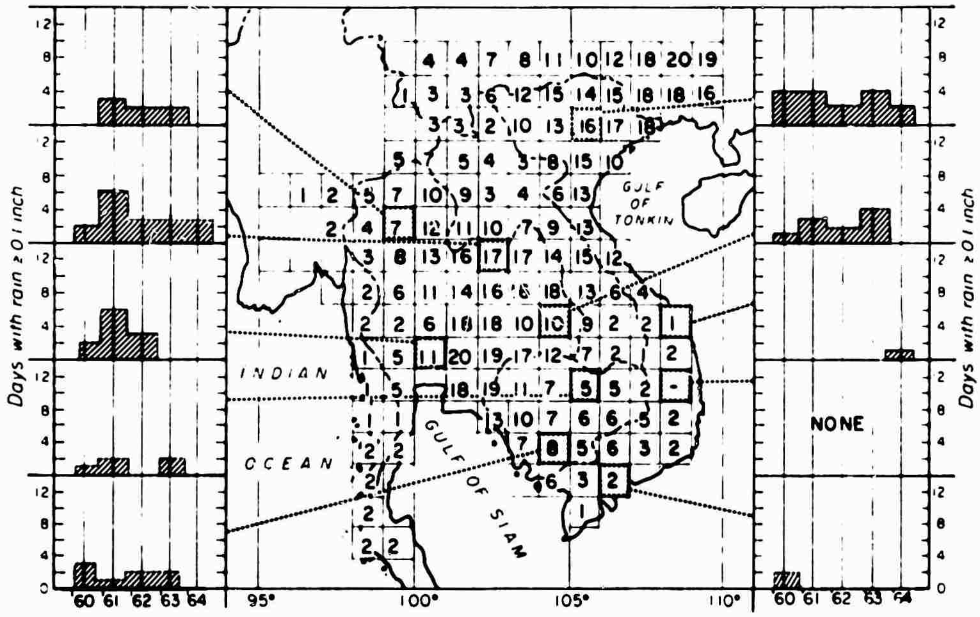

Figure 7.--Total number of days in March, during a 5-year period, general rain fell within each 1-degree square. Histograms show the number of days of general rain, by year, for 10 random squares.

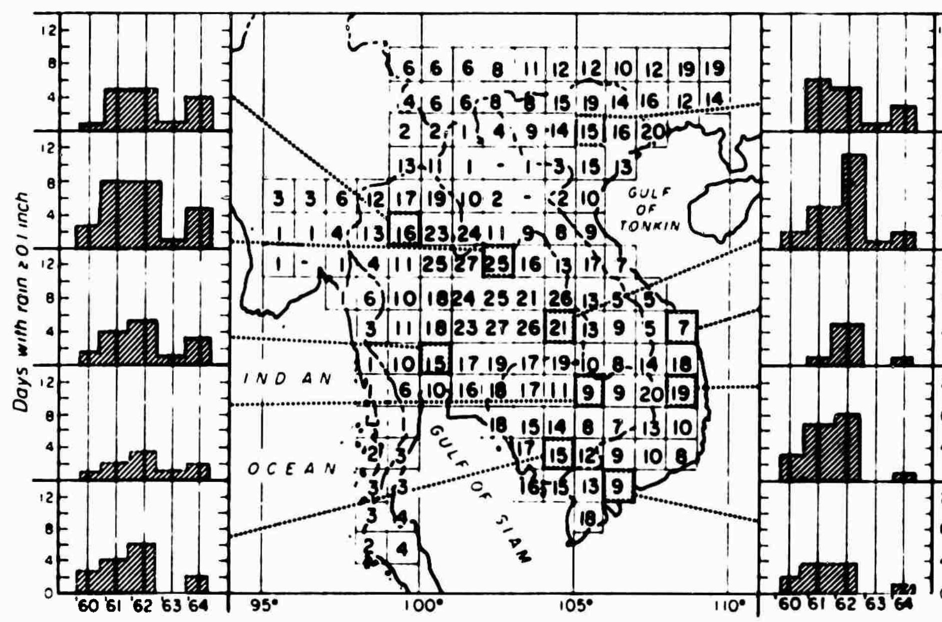

Figure 8.--Total number of days in April, during a 5-year period, general rain fell within each 1-degree square. Histograms show the number of days of general rain, by year, for 10 random squares.

SYNOPTIC-SCALE DISTURBANCES

In the early part of the normally dry period in SEA tropical cyclones and easterly waves move westward south of the subtropical ridge and can cause rain. A trough in the westerlies can deepen over the area and sometimes cause rain. Also, an easterly wave, which might produce little or no rain by itself, can cause considerable rain if there is a superposition of a trough in the westerlies on the easterly wave. A strong surge of the northeast monsoon across the Annam Mountains can form a lee trough that moves westward like an easterly wave and causes rain. Later in the period, tropical troughs moving eastward at high levels intensify over Burma, Thailand, and Indochina and extensive rain usually occurs east of the trough line.

Case histories illustrate these five types of synoptic-scale weather disturbances.

Tropical Cyclone

General Rain 30 November 1962

Moderate to heavy rainfall covered a large portion of South Vietnam on 30 November 1962 (fig. 9). On 1 December considerable rain continued to fall along the coast of South Vietnam and Cambodia, but little or none inland (fig. 10). By 2 December the only rainfall of any consequence occurred along the east coast of Thailand.

Formation and Development of Tropical Cyclone

An equatorial vortex--a closed cyclonic circulation within the equatorial trough[1]--was first detected at 3.5°N. and 148°E. on the surface analysis for 1200 G.m.t., 22 November 1962 (fig. 11). It probably developed from one of the undetected equatorial waves which often form over the western Pacific Ocean. The 300 mb. analysis shows the vortex developed under an area of fairly strong divergence in the upper levels (fig. 12).

The equatorial vortex was under the influence of the equatorial easterlies, which carried the vortex westward. By 0000 G.m.t. on 25 November 1962 the vortex had moved to 6.5°N. and 136.5°E., where it became a tropical depression. The Joint Typhoon Warning Center at Guam labeled the disturbance Tropical Depression 86, but the title was short-lived, because by about 0600 G.m.t. the depression had become a tropical storm. . .Tropical Storm Lucy. By then Tropical Storm Lucy was about 180 miles east-southeast of Koror Island, Palau Islands.

Movement of Tropical Cyclone

Tropical Storm Lucy continued to move west about 18-20 miles per hour and passed about 30 miles south of Koror Island, around 1500 G.m.t. on 25 November 1962 (fig. 13). Heights fell, then began

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[1]American Meteorological Society. Glossary of meteorology. p. 206. 1959. Boston, Mass.

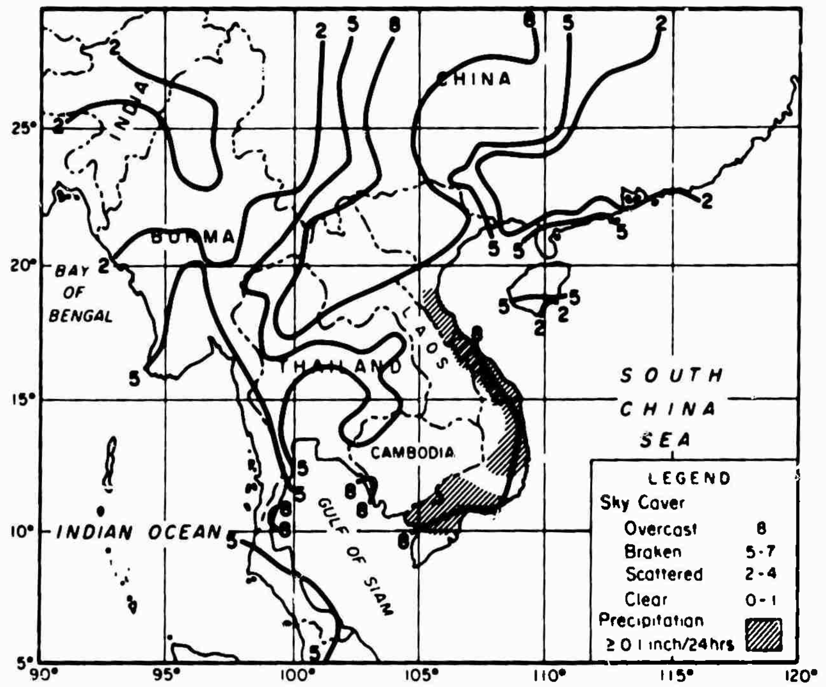

Figure 9.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 30 November 1962.

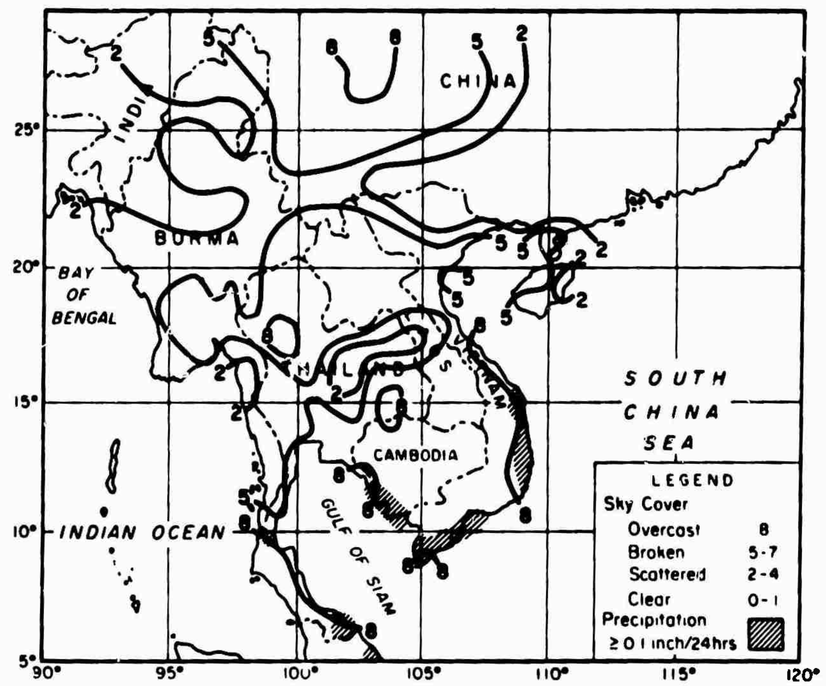

Figure 10.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 1 December 1962.

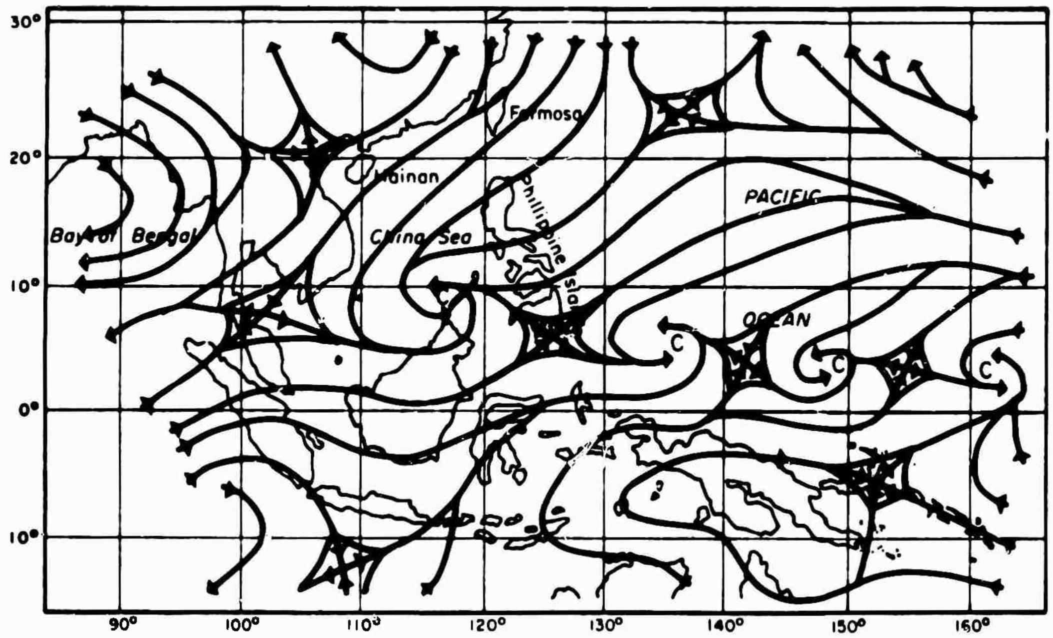

Figure 11.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 1200 GMT, 22 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam).

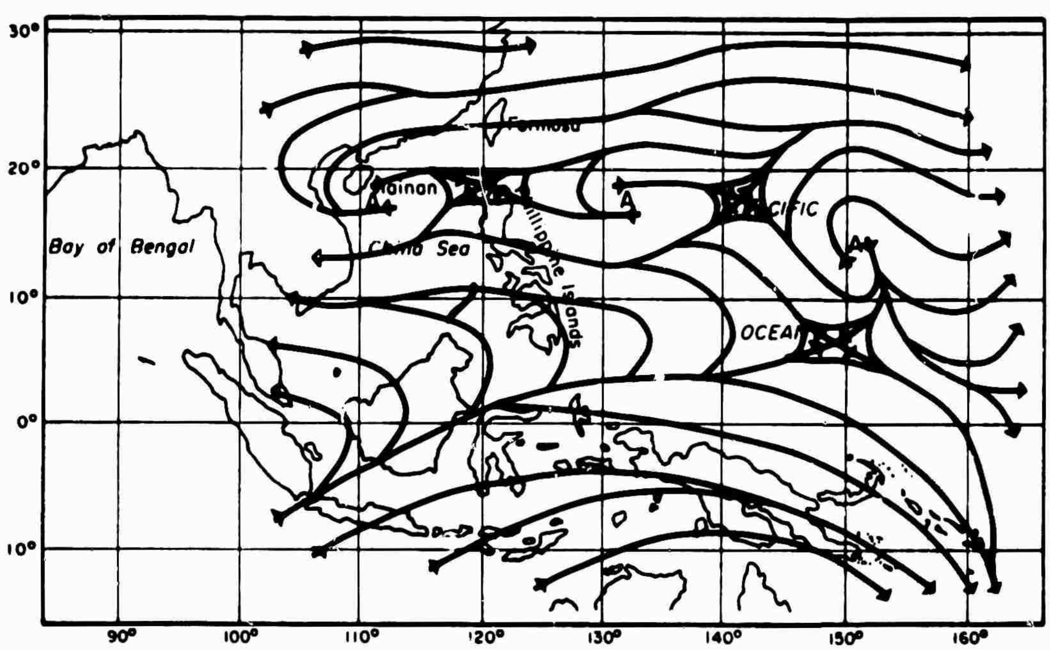

Figure 12.--300 mb. streamline analysis at 1200 GMT, 22 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

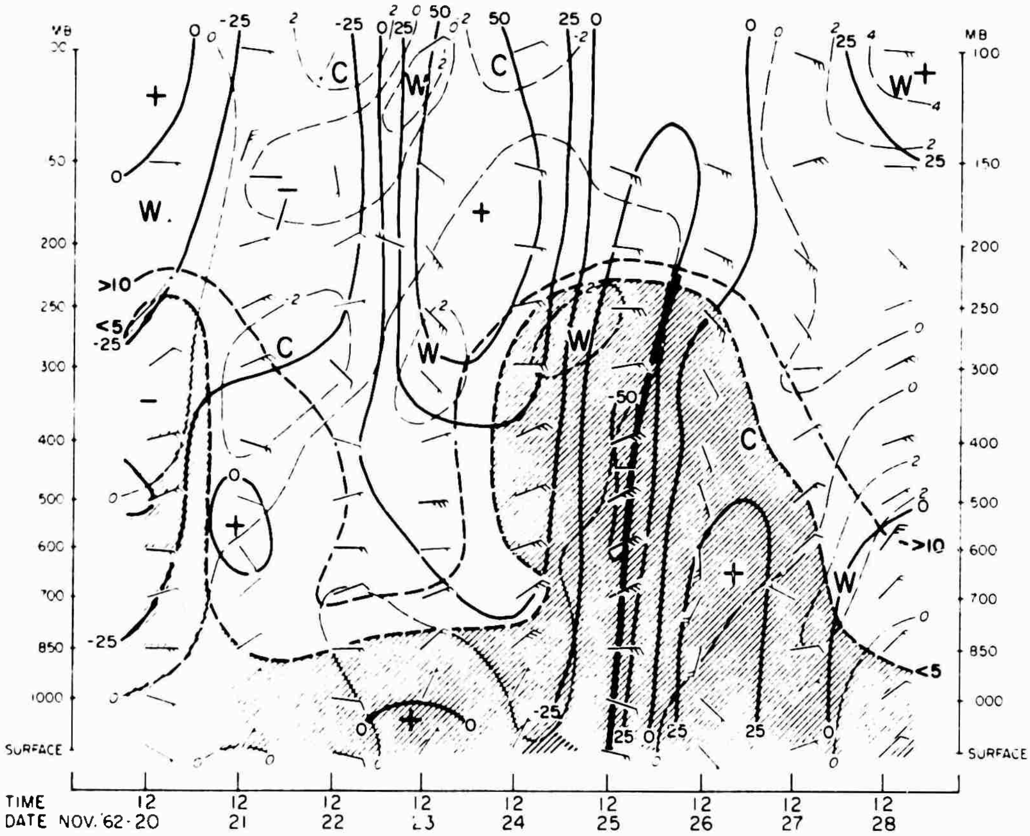

Figure 13.--Vertical time cross-section at Koror Island, 20-28 November 1962, shows 24-hour changes in height, in meters (heavy solid lines), and in temperature, in °C (thin dashed lines); and boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C depression (shaded).

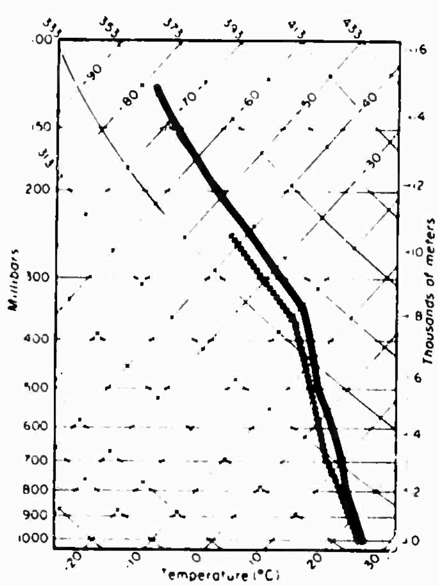

Figure 14.--Skew T, Log P Diagram for Koror Island at 1200 GMT, 25 November 1962. Temperatures given by solid line and dewpoint by dashed line.

to rise as the storm passed. The winds shifted very sharply with the passage. A very deep, moist layer at Koror moved in about a day and a half before the storm passed and remained until the day after. The sounding taken at Koror at 1200 G.m.t. on 25 November, just before the storm passed, showed that this layer extended to 250 mb. (fig. 14). The vertical temperature distribution for Koror Island is similar to the one Riehl (1954) associated with the rain area of a tropical cyclone. The temperature sounding is the same as one traced by an air particle raised dry-adiabatically to condensation, then moist-adiabatically to about 300 mb.

After Tropical Storm Lucy passed Koror Island it began moving west-northwest and by 0000 G.m.t. on 26 November, it was near 7.5° N. and 131°E. (fig. 15). Tropical Storm Lucy became Typhoon Lucy about 0000 G.m.t. on 27 November, just as it started to pass the Philippine Islands. At about 0900 G.m.t. that day, the storm passed just a few miles north of Cebu and by 1200 G.m.t. a quarter inch of rain fell. Typhoon Lucy then began to move more to the west. On the 28th at 0000 G.m.t. it was located at 10.5°N. and 120°E. (fig. 16). The circulation around Typhoon Lucy became much more intense, with maximum surface winds reported to be almost 75 knots. And the typhoon covered a much smaller area than it had on the 26th (fig. 15). Growing more intense as it moved westward, Typhoon Lucy passed Palawan Island about 0600 G.m.t. on the 28th. Puerto Princesa, Palawan Island, about 75 miles south of Lucy's track, reported over a half inch of rain between 0600 and 1200 G.m.t.

Typhoon Lucy reached its maximum intensity about 1200 G.m.t. on 29 November, when 100 knot surface winds were reported. During this peak intensity, Lucy slowed to about 10 m.p.h. but continued to move west, and by 0000 G.m.t. on 30 November the disturbance was located at 10°N. and 110°E. (fig. 17). At this time, the typhoon had surface winds of 90 knots and was about 225 miles east-southeast of Saigon. Moderate to heavy rain fell over much of South Vietnam on the 30th as Lucy moved west along 10°N. latitude. The typhoon began to lose intensity and became a tropical storm about 0600 G.m.t. on 30 November. Tropical Storm Lucy passed about 50 miles south of Saigon. The storm center passed south of Saigon shortly before 1200 G.m.t. on the 30th (fig. 18). Very strong winds in the middle troposphere were associated with the tropical storm. As it passed, the winds from the 850 mb. level through the 200 mb. level shifted, and the heights above 850 mb. rose sharply. The moist layer was evident up to 300 mb.

As the tropical cyclone continued to move west, it had already begun to weaken. By 0000 G.m.t. on 1 December the surface winds were less than 30 knots and the storm became a tropical depression. On 1 December, as the storm moved to the west across the Gulf of Thailand, rainfall occurred only along the southwest coast of South Vietnam. The track of Typhoon Lucy prepared by the Joint Typhoon Warning Center shows that the disturbance was dropped at 1800 G.m.t. on 1 December 1962 (fig. 19).

The disturbance, however, did not die completely, but moved

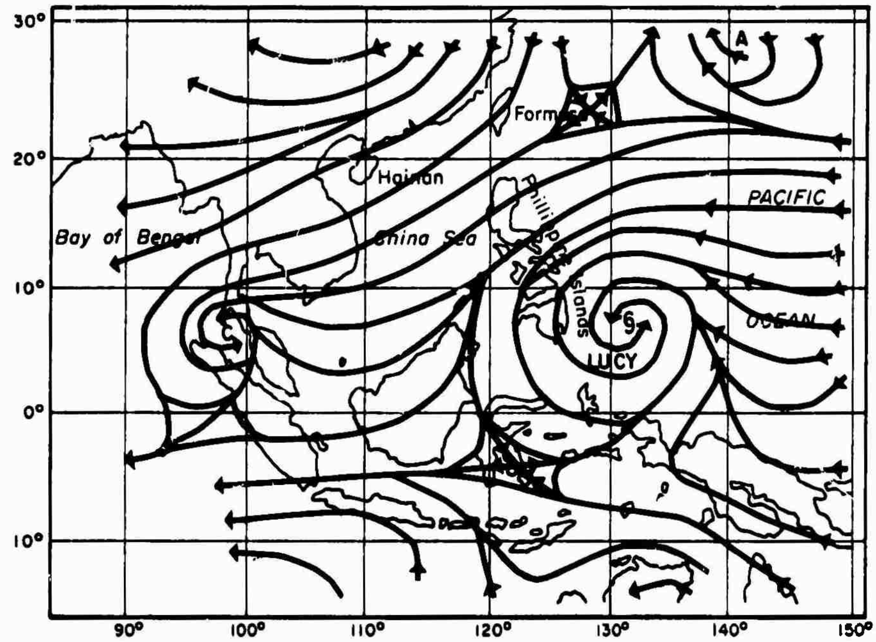

Figure 15.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 0000 GMT, 26 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

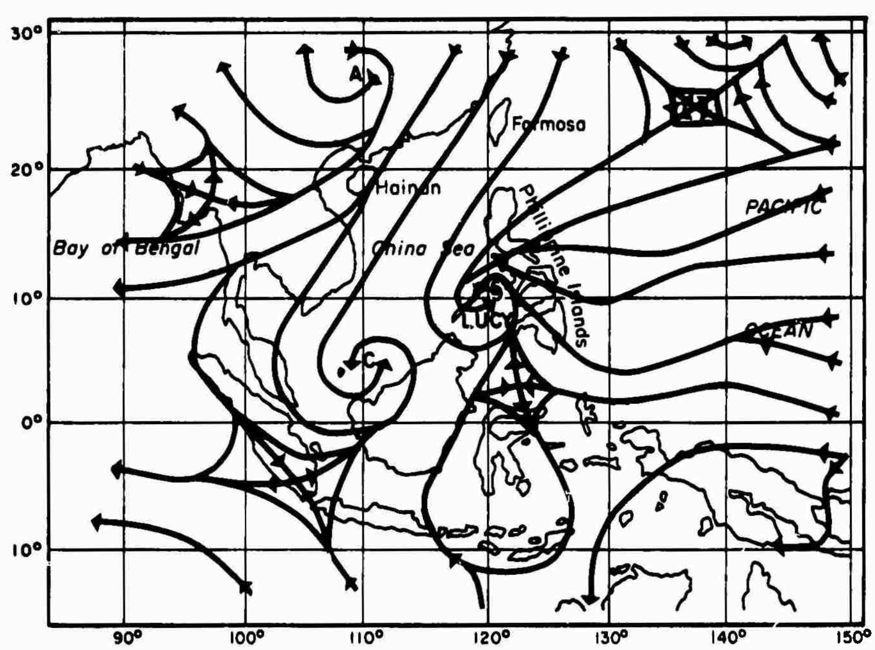

Figure 16.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 0000 GMT, 28 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB Guam.)

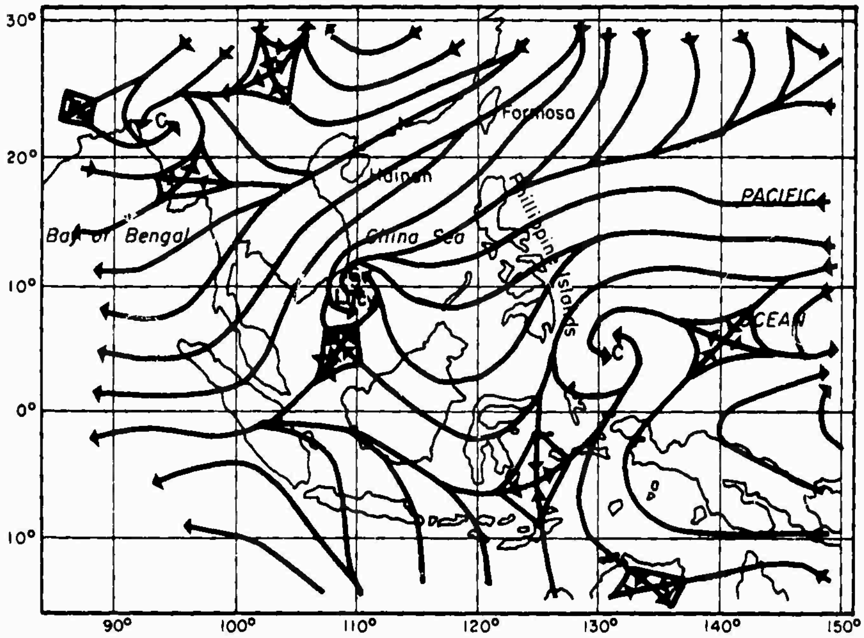

Figure 17.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 0000 GMT, 30 November 1962. Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

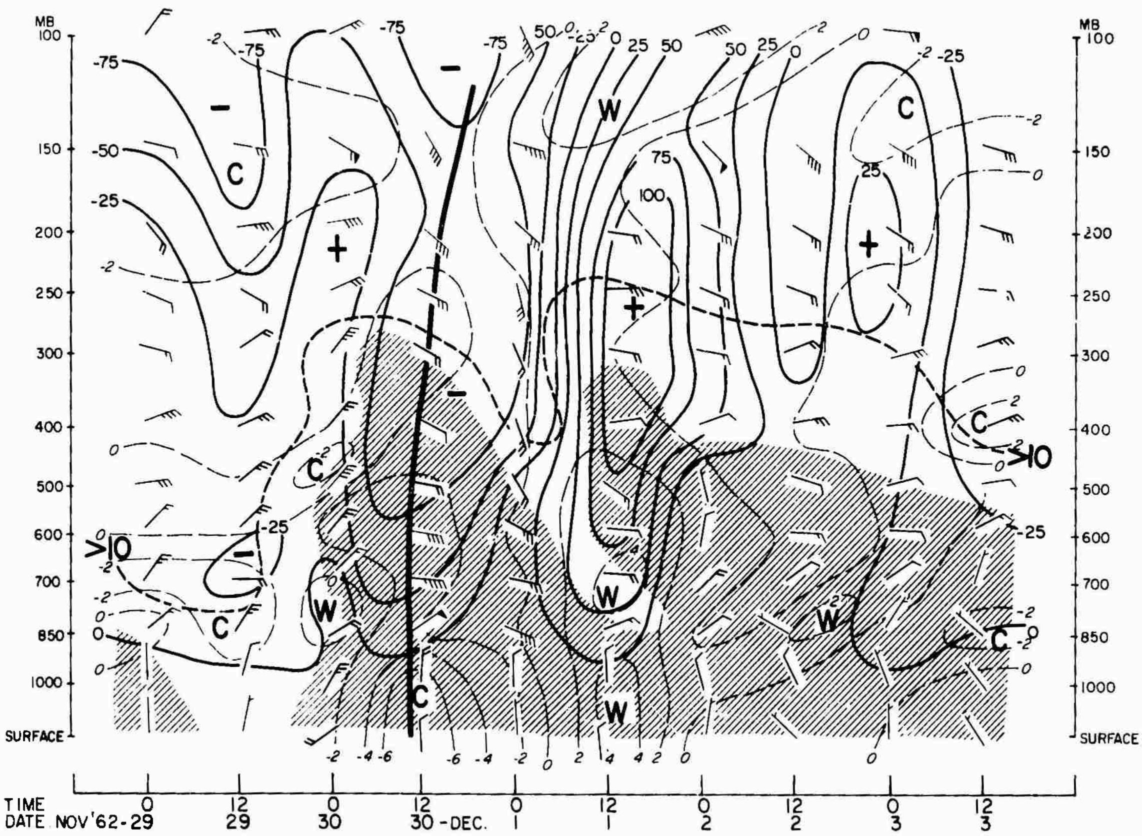

Figure 18.--Vertical time cross-section at Saigon, Vietnam, 29 November-3 December 1962, shows 24-hour changes in height, in meters (heavy solid lines), and in temperature, in °C (thin dashed lines); and boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C depression (shaded).

across the peninsula of Thailand and Burma and into the Andaman Sea. It then moved west across the Bay of Bengal, where it was described as a "fresh easterly wave" by Ranganathan and Soundararajan (1965).

Typhoon Lucy Responsible for Rain

At 0000 G.m.t. on 30 November 1962, Typhoon Lucy was located at 10°N. and 110°E. with a closed cyclonic circulation at 300 mb. (fig. 20). A closed cyclonic circulation at this level is not unusual. Riehl (1954), for example, reported that cyclonic circulation can be expected in mature storms up through 300 mb., but above 300 mb. the flow is most often anticyclonic. In analyzing an east-west vertical space cross-section for 0000 G.m.t., 30 November (fig. 21), we found the typhoon between two anticyclones. The height at 700 mb. was 300 meters below the height of the tropical atmosphere given by Fehlner et al. (1958). The V-shape of potential temperatures showed warm air in the typhoon up through 250 mb. and a dome of cold air above. The soundings taken at Saigon at 0000 G.m.t., while the typhoon was over the South China Sea, and at 1200 G.m.t., just after the storm had passed, showed cooling below 300 mb. and a large increase in moisture when Lucy passed (figs. 22, 23). The atmosphere was rather stable before, during, and after passage, with a Showalter Index at Saigon of 4.5 at 0000 G.m.t. and 4.0 at 1200 G.m.t.

As Typhoon Lucy moved toward the coast of South Vietnam and across the lowlands moderate to heavy rain fell over the east coast and most of southern South Vietnam. Very heavy precipitation was lacking--possibly because (1) the storm was decaying, (2) the high speed of the storm (near 20 miles per hour), and (3) the somewhat stable atmosphere within and around the storm.

Trough in the Westerlies

General Rain 21-23 March 1963

On 21 March 1963 general rain occurred over an area about 33,000 square miles in eastern Thailand and small parts of Laos and Cambodia (fig. 24). By the 22nd the rain area had dwindled to a little more than 20,000 square miles, but had spread farther south into Cambodia (fig. 25). The general rain area on the 23rd, however, again covered about 30,000 square miles on a narrow strip along the Mekong River (fig. 26).

Movement of the Trough in the Westerlies

A trough was observed in the westerly flow at 300 mb. over Egypt at 0000 G.m.t. on 11 March 1963. It continued to move eastward, and by 0000 G.m.t. on 15 March it had deepened and extended to 10°N. over the Arabian Sea (fig. 27).

The trough continued to move east, and at the 300-mb. level it passed Bombay at about 1800 G.m.t. on 15 March (fig. 28). The trough is indicated by the zero height-change line where height had just fallen, then risen. However, Riehl (1954) suggests that 24-hour changes, when plotted at the end of the 24-hour interval

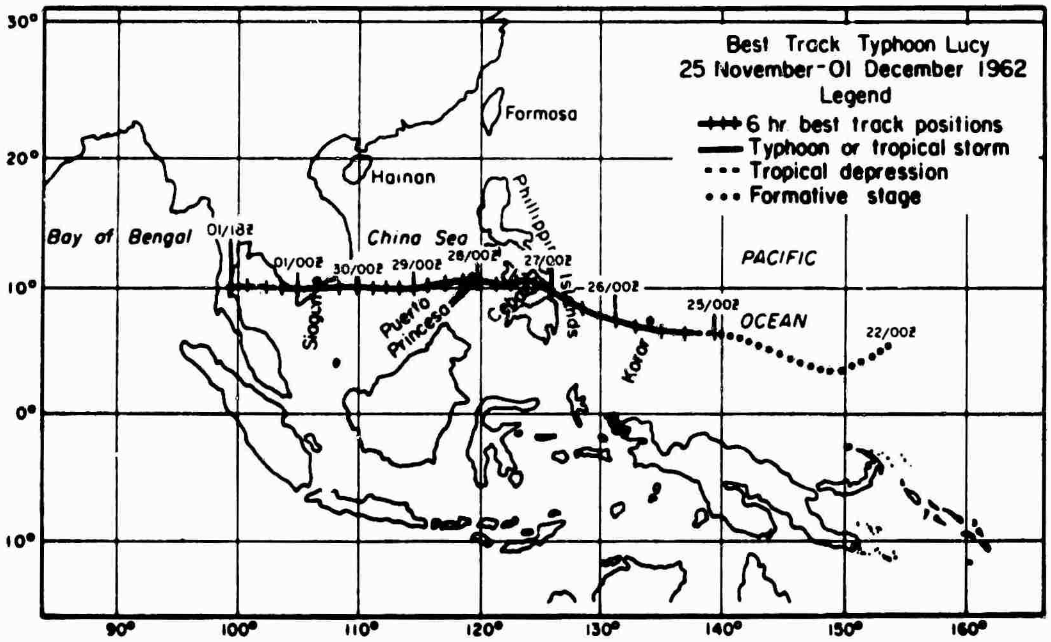

Figure 19.--Best track of Typhoon Lucy, 25 November-1 December 1962. (Prepared by Joint Typhoon Warning Center, Guam.)

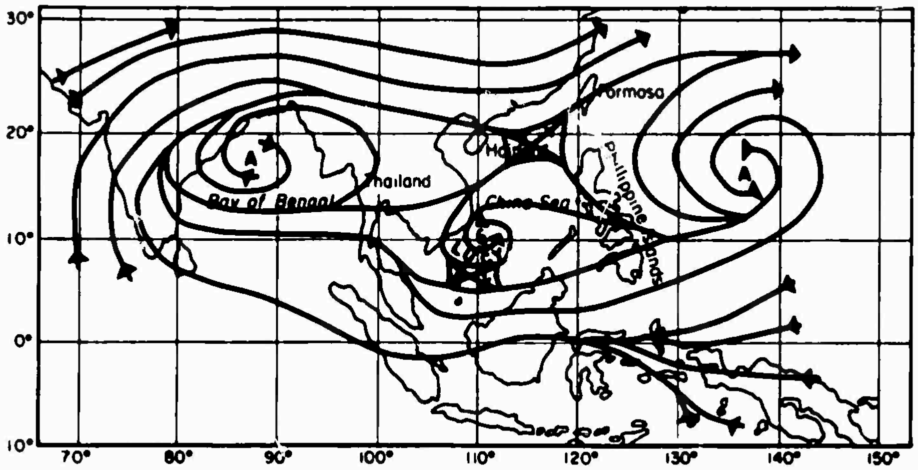

Figure 20.--300 mb. streamline analysis at 0000 GMT, 30 November 1962.

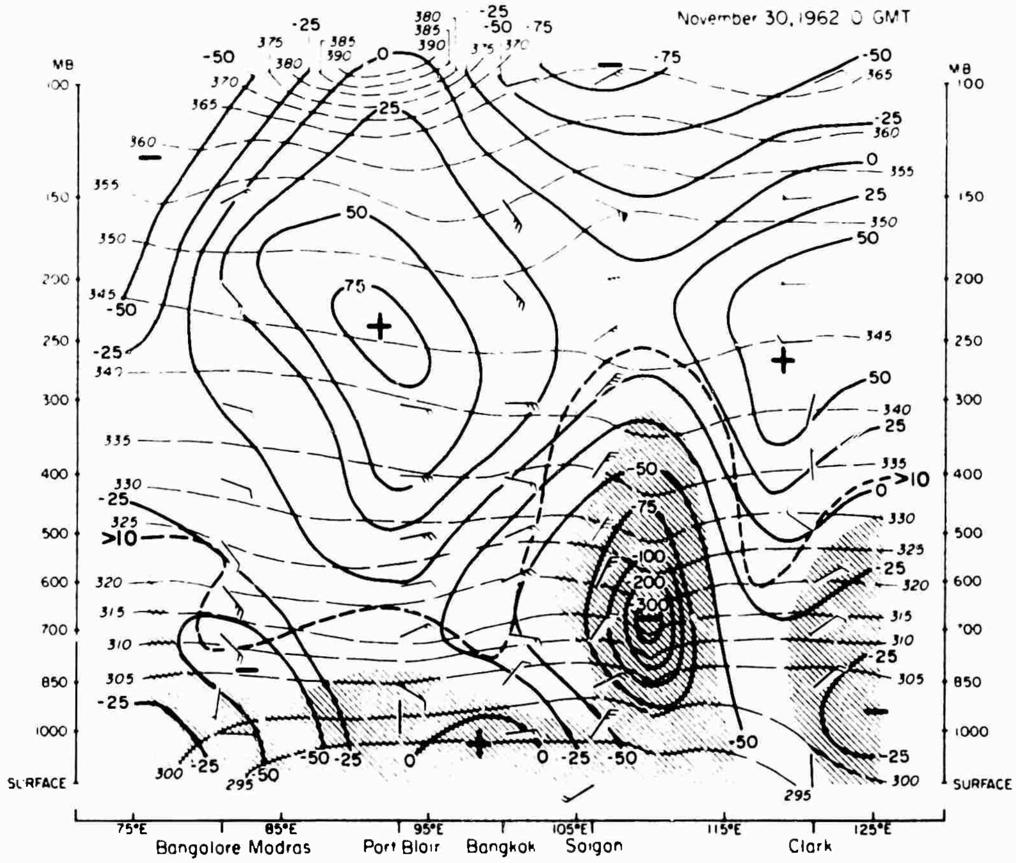

Figure 21.--Vertical space cross-section of "D" Values in meters (solid lines), potential temperature in °K (thin dashed lines), boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

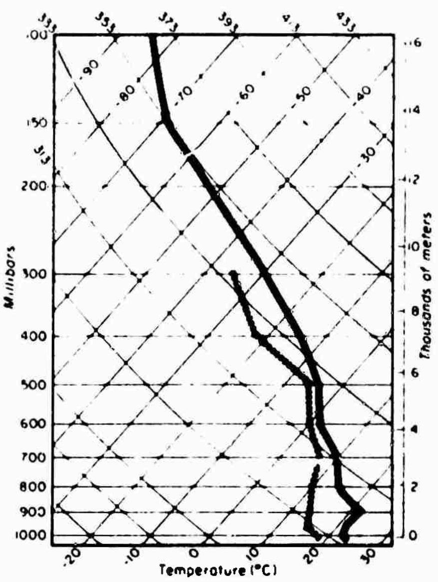

Figure 22.--Skew T, Log P Diagram for Saigon, Vietnam at 0000 GMT, 30 November 1962. Temperatures given by solid line and dewpoint by the dashed line.

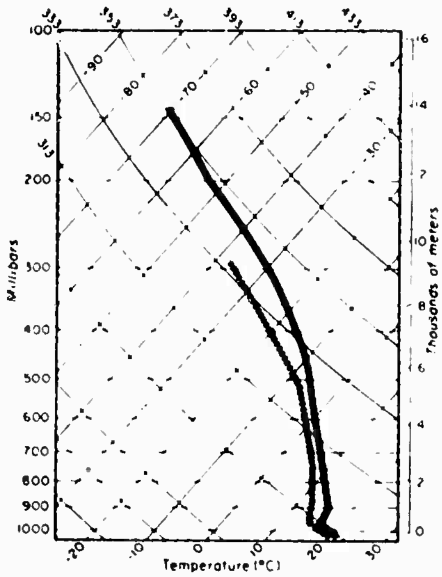

Figure 23.--Skew T, Log P Diagram for Saigon, Vietnam at 1200 GMT, 30 November 1962. Temperatures given by solid line and dewpoint by the dashed line.

as was done in this study, should be mentally moved back 12 hours to indicate instantaneous tendency. The graph (fig. 28) shows the zero line passing Bombay at 300 mb. at 0600 G.m.t. on the 16th. And so the trough passed at 1800 G.m.t. on the 15th. It was followed by a veering of the wind, but the moist layer did not change significantly. The trough continued its eastward movement and was over the Bay of Bengal at 0000 G.m.t. on the 18th (fig. 29). It passed Bangkok at the 300-mb. level at about 0000 G.m.t. on the 21st. On this date general rain occurred about 100 miles ahead of the trough line. By 0000 G.m.t. 22 March 1963 the trough had deepened somehwat and moved to the central part of SEA at 103°E. (fig. 30). With this deepening, the rain spread farther south and fell almost immediately ahead of the trough line. The trough lay over the Mekong River on the 23rd, and an area of rain occurred in a narrow band along the river.

By 0000 G.m.t., on 25 March the trough had moved into the China Sea (fig. 31). It finally dissipated on 27 March while still over the same area.

Trough in the Westerlies Responsible for Rain

On 21 March 1963, the polar front across south China moved into the China Sea and was activated, and general rain occurred (fig. 32). At the same time a low-pressure cell formed on the front in northwest Thailand and was reflected in the streamlines at 600 meters (fig. 33). Low-level convergence became evident over the area. The low-level convergence continued on the 22nd (fig. 34), and, at the same time, high-level divergence occurred ahead of the trough at the 300-mb. level (fig. 30). The trough at 300 mb. was located at 103°E. (fig. 30) and the rain areas for the 22nd (fig. 25) extended northeastward from the trough line over the area of low-level convergence and high-level divergence. Broken to overcast clouds occurred with the rain east of the trough, but, to the west, only scattered clouds were observed.

Vertical space cross-sections for 0000 G.m.t., 22 March 1963 were analyzed along east-west axes (figs. 35 and 36). The Bangalore-Clark cross section (fig. 35) displays two high-pressure areas in the high troposphere centered over Madras and east of Clark Air Force Base. These high-pressure areas override flow that is generally easterly, showing that the trough did not extend this far south in the low levels. The trough does show up, however, at 200 mb. and above, over Bangkok and Saigon, and it appears to have connected with the easterly flow below. Cold air, as indicated by the dome of potential temperatures in this area above 700 mb., overrides a moist layer that extends up to 650 mb. The Bombay-Guam cross-section shows a deep, broad trough extending from Bombay to Danang, with a large high pressure area situated between Clark and Guam (fig. 36). Cold air in the trough is shown by the potential temperatures between Chaingmai and Danang. The cold air is most pronounced between 850 and 400 mb. and overrides a fairly deep, but narrow, moist layer. The general rain occurred just ahead of the trough line as indicated on this cross-section and just to the south of its transection.

With this trough in the westerlies, high-level divergence overlaid low-level convergence ahead of the trough. This overlay caused the polar front activity and ascent of moist unstable air, which in turn caused the general rain.

Superposition of a Trough in the Westerlies on an Easterly Wave

General Rain 24-25 November 1962

The precipitation and cloud cover maps show general rain over much of South Vietnam, parts of Cambodia, and the southern peninsula of Thailand on 24 and 25 November 1962 (figs. 37, 38). By the 26th, most of the rain had moved out of South Vietnam and Cambodia. Heavy rain, however, fell along the east coast of the Thailand Peninsula, with one station reporting 4.72 inches.

Formation of the Easterly Wave

On 17 November 1962, a trough in the westerlies moved into the China Sea and deepened (fig. 39). It extended well into the tropics and became what Cressman (1948) calls an "extended trough." A wave formed under this trough in the convergence zone between the northeast monsoon, the North Pacific Trades flowing across the Philippines, and the Southwest Trades from the Southern Hemisphere (fig. 40). The wave became a closed circulation immediately, and on 18 November 1962 was labeled Tropical Depression 85 by the Joint Typhoon Warning Center at Guam.

Movement of the Easterly Wave

The wave moved slowly south-southwest and began to weaken as the subtropical ridge at 300 mb. moved north to its original position near 17°N. The label Tropical Depression 85 was removed on 20 November. After reaching 5°N. and 115°E. the wave remained stationary for 2 days (fig. 41). The wave began to move west and deepen as a new surge of the northeast monsoon arrived over the China Sea (fig. 42). This surge increased the north-south pressure gradient and strengthened the easterly flow over the China Sea. The easterly wave moved very slowly on the 22nd and 23rd, but as the strength of the northeast monsoon increased the easterly wave increased its westward movement. The wave passed south of Saigon near 0000 G.m.t. on 24 November (fig. 43). The passage is indicated by pressure falls ahead of the wave, and by pressure rises behind. As mentioned before, the 24-hour changes, when plotted at the end of the 24-hour interval as was done here, should be mentally moved back 12 hours to indicate instantaneous tendency. No rainfall occurred on the 23rd but moderate to heavy rain fell in southern South Vietnam and Cambodia on the 24th and 25th after the wave passed. A deep moist layer was associated with this easterly wave, and the wind shifts show that the wave extended to well above 300 mb. (fig. 43).

The easterly wave continued to move west and passed Songkhla about 1200 G.m.t. on the 25th (fig. 44). The deep moist layer, the height to which the wave extends, and the very heavy precipitation along the coast of the peninsula of Thailand on the 26th give evidence of the strength of this easterly wave.

The wave moved across the peninsula and into the Andaman Sea on the 26th (fig. 45). It continued to move west and by 0000 G.m.t. on 27 November was at 5°N. and 95°E. The flow at 300 mb. indicates that this easterly wave continued to move west across the Bay of Bengal and arrived over the Indian Peninsula on 1 December. Ranganathan and Soundararajan (1965) have reported on the interaction of this easterly wave with a westerly trough.

Trough in the Westerlies

As the wave moved across the South China Sea on 24 November a trough in the westerlies was moving across northern Burma (fig. 46). As the trough approached Laos and North Vietnam the heights above 300 mb. began to drop sharply on 24 November (fig. 47). The trough deepened and passed Hanoi about 1800 G.m.t. on the 24th. The trough passage at Hanoi was followed by a wind shift, a slight pressure rise, and an increase of temperature at 300 mb. On the 25th, the trough continued to deepen; its extension to the south into South Vietnam is evidenced by the 300 mb. streamlines (fig. 48). By the 27th, the trough had moved to the east and began to fill as an anticyclone began to build over Southeast Asia.

Superposition of the Trough in the Westerlies on the Easterly Wave Responsible for Rain

Moderate to heavy rain fell over southern South Vietnam and Cambodia after the easterly wave passed. The vertical time cross-section for Saigon showed that the easterly wave extended to above 300 mb. and produced a very deep moist layer (fig. 43). Because this wave passed some 300 miles south of Saigon, its strength near the center must have been enormous.

Why such a strong easterly wave? Riehl and Shafer (1944) show that superposition of a trough in the westerlies on an easterly wave often results in intensification of both.

Therefore, the moderate to heavy rain in South Vietnam and Cambodia on the 24th and 25th and the deepening of the trough in the westerlies and its extension into South Vietnam must have been caused by an interaction between the easterly wave and the trough. Thus a superposition of the trough in the westerlies on the easterly wave very likely occurred over Southeast Asia on the 24th and 25th of November 1962.

(Text continued on page 38)

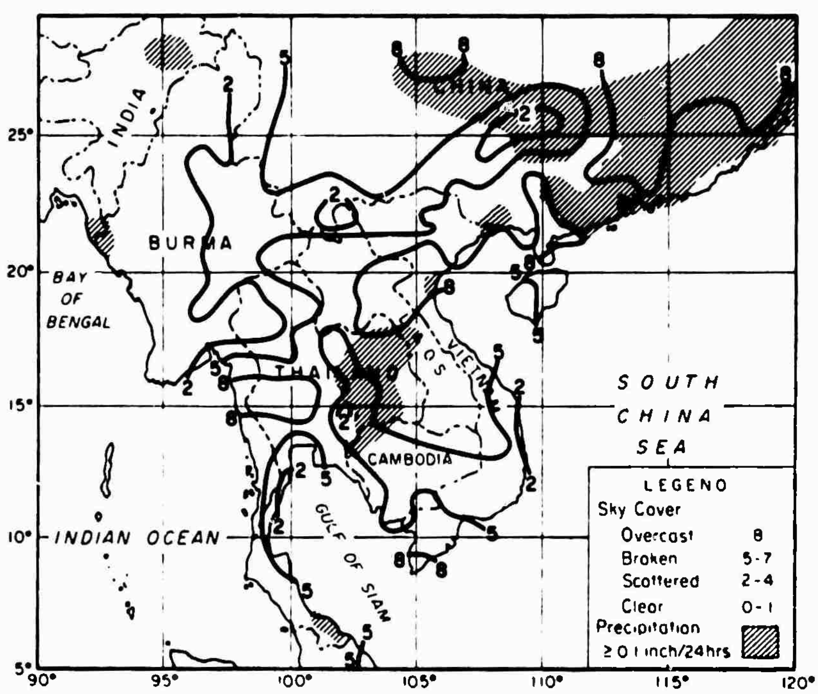

Figure 24.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 21 March 1963.

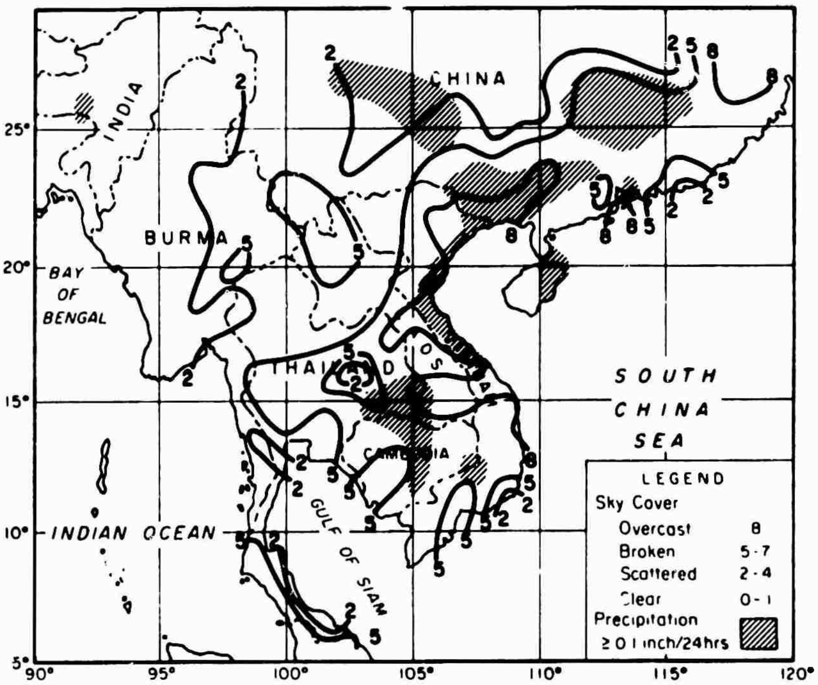

Figure 25.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 22 March 1963.

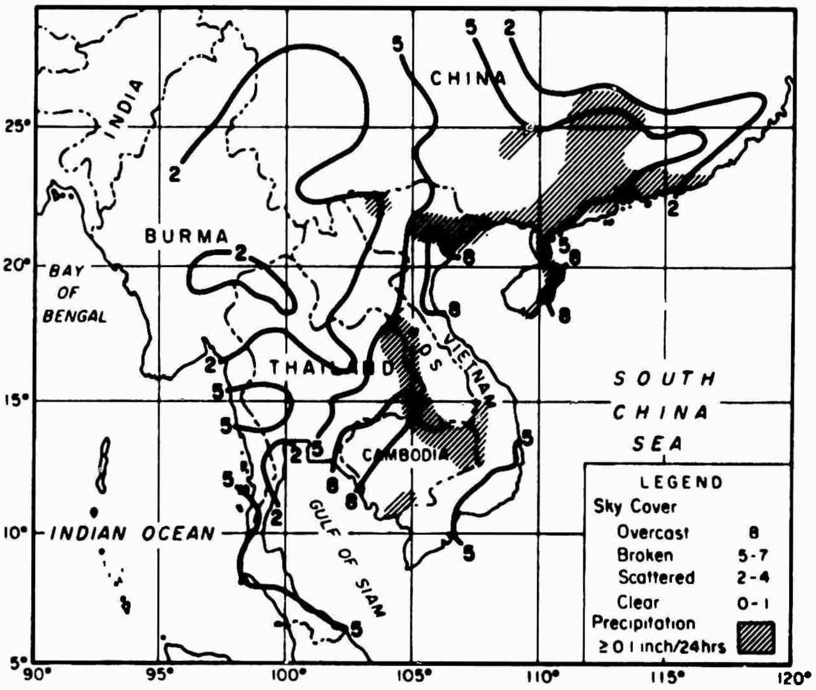

Figure 26.--Analysis for 24-hour precipitation and 0600 GMT total cloud cover for 23 March 1963.

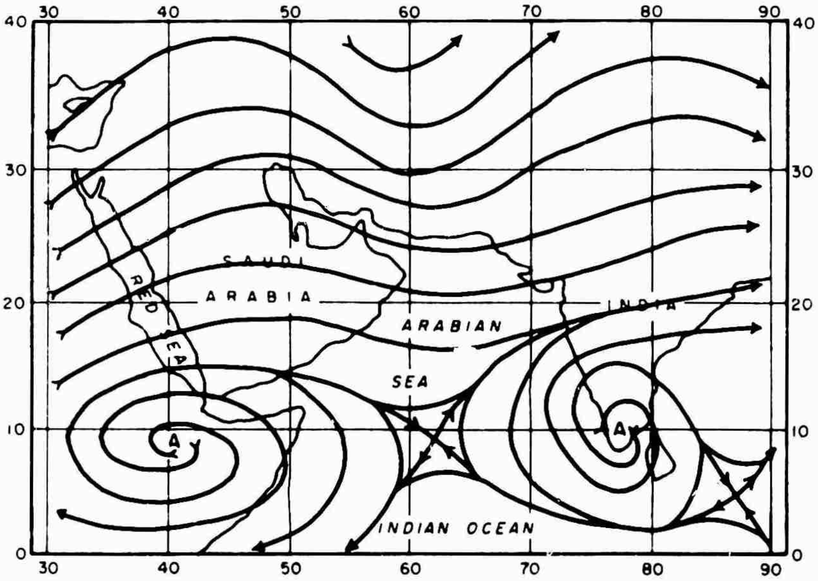

Figure 27.--300 mb. streamline analysis at 0000 GMT, 15 March 1963. (Analyzed by Indian Meteorological Centre, Bombay, India.)

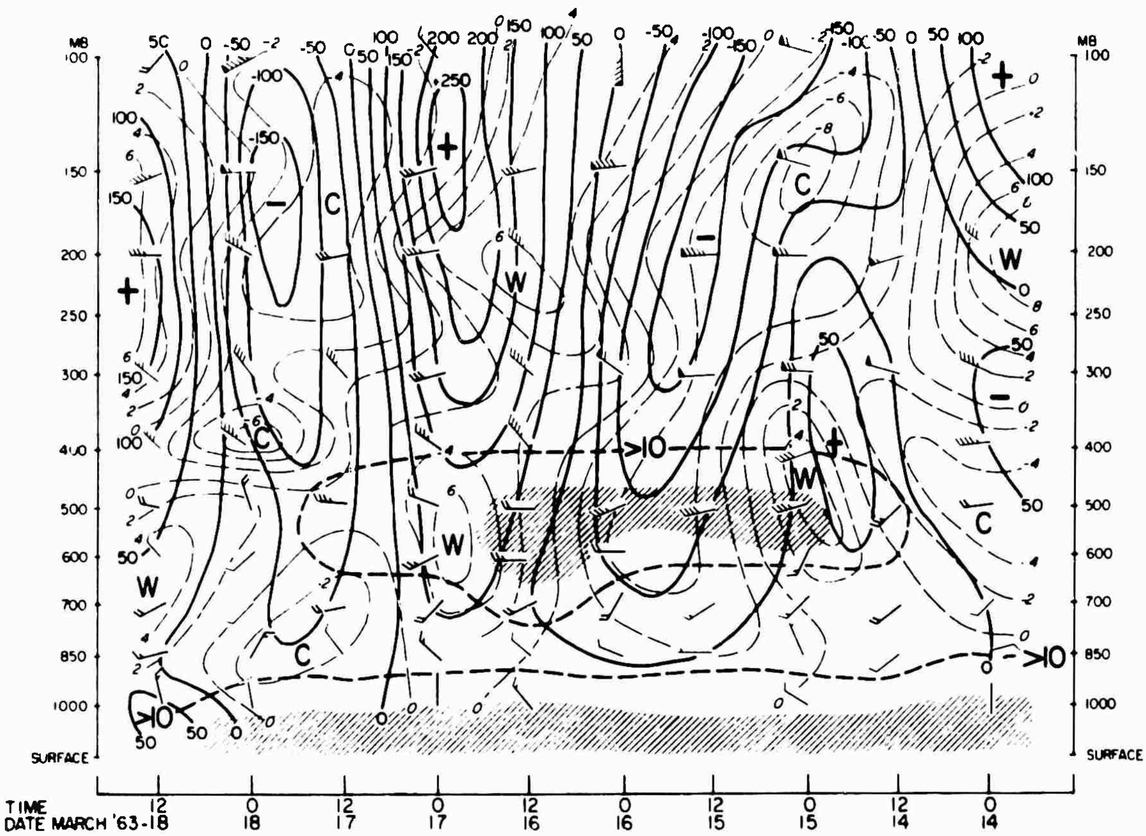

Figure 28.--Vertical time cross-section at Bombay, India, March 14-18, 1963, shows 24-hour changes in height, in meters (heavy solid lines), and in temperature, in °C (thin dashed lines); and boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C depression (shaded).

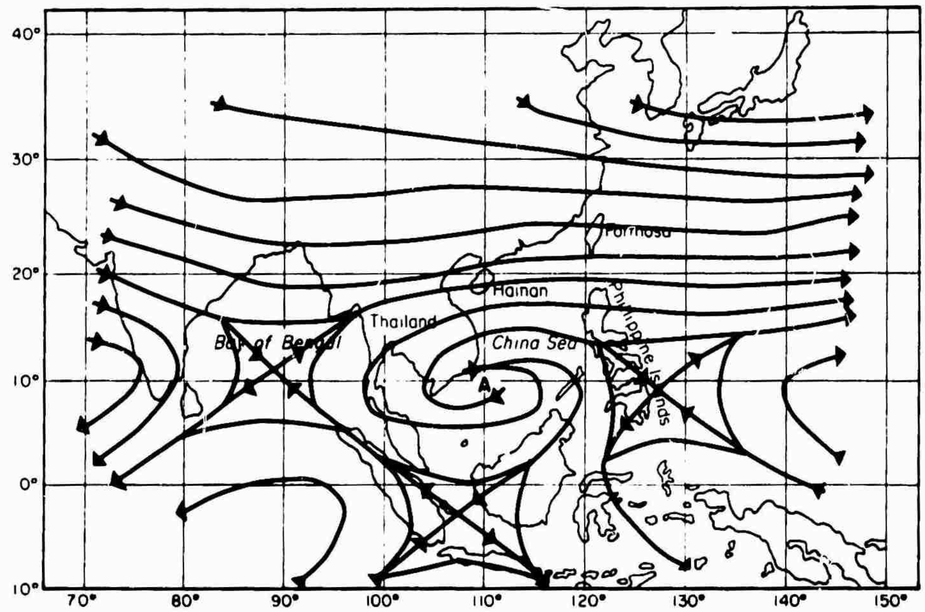

Figure 29.--300 mb. streamline analysis at 0000 GMT, 18 March 1963. (Analyzed by Thailand Meteorological Department.)

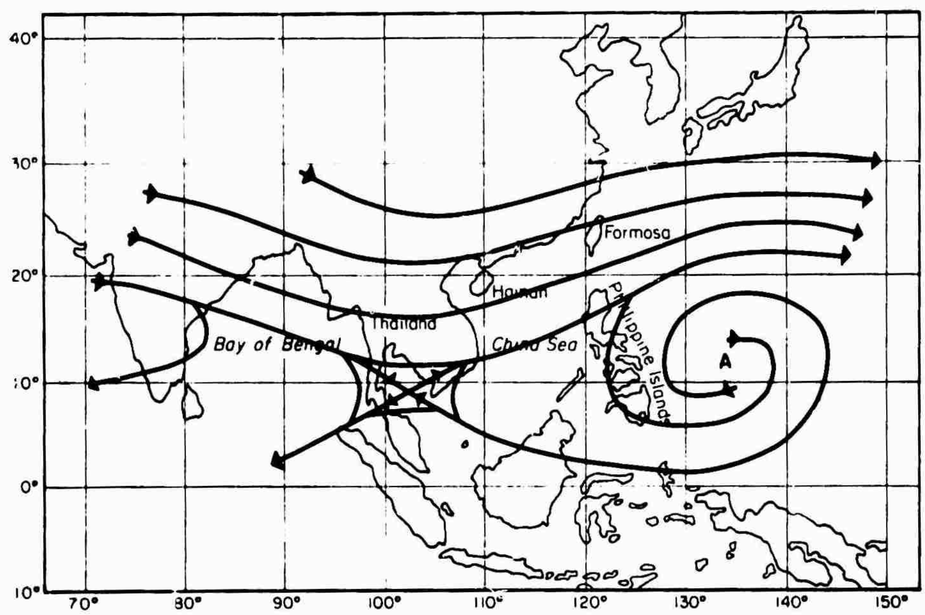

Figure 30.--300 mb. streamline analysis at 0000 GMT, 22 March 1963. (Analyzed by Thailand Meteorological Department.)

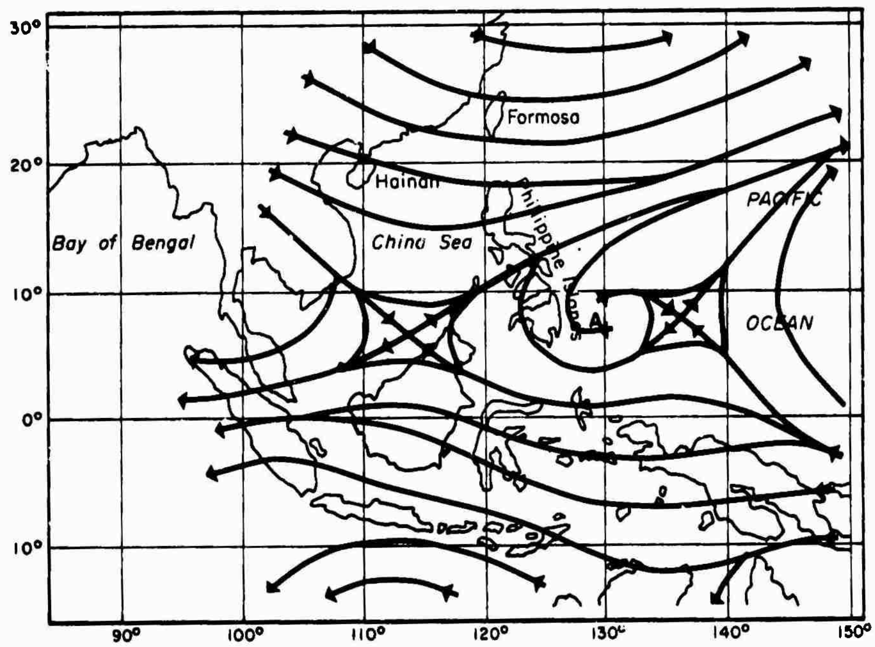

Figure 31.--300 mb. streamline analysis at 0000 GMT, 25 March 1963. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

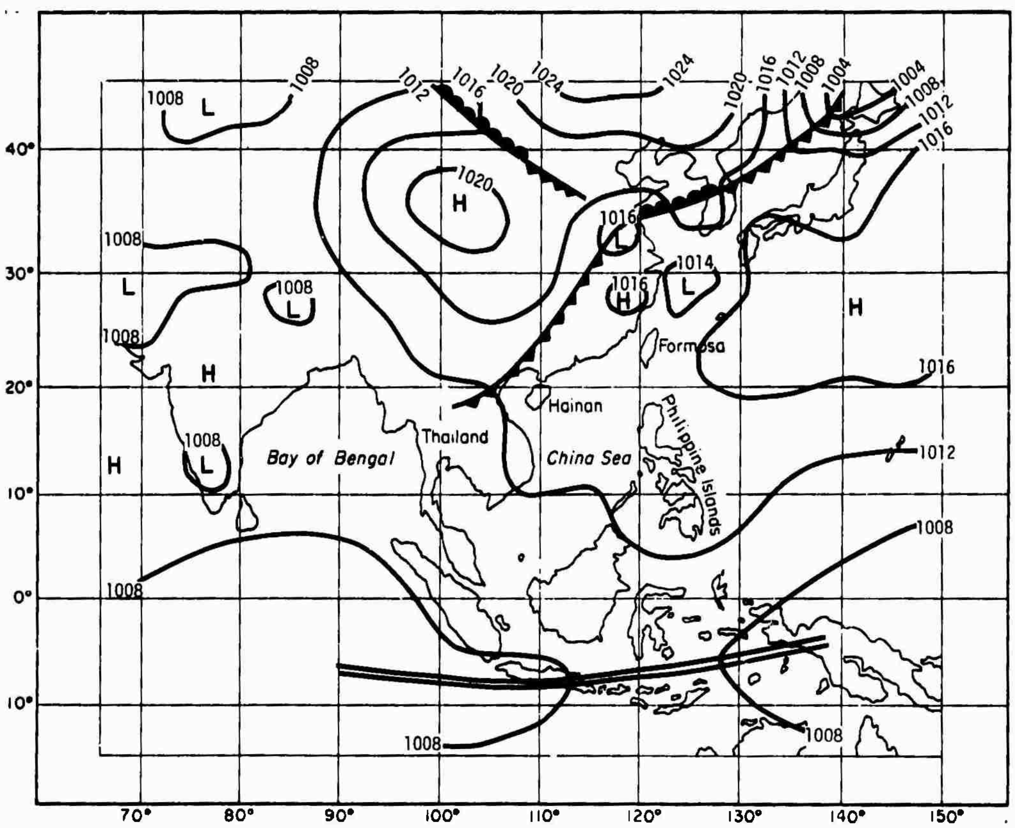

Figure 32.--Surface analysis at 0000 GMT, 21 March 1963 (analyzed by Thailand Meteorological Department).

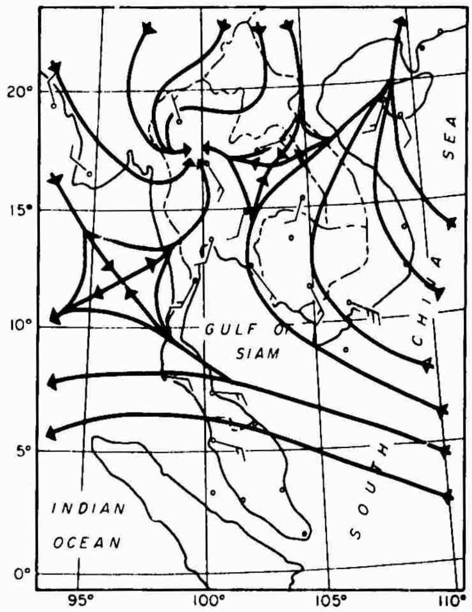

Figure 33.--600-meter streamline analysis at 0000 GMT, 21 March 1963 (analyzed by Thailand Meteorological Department).

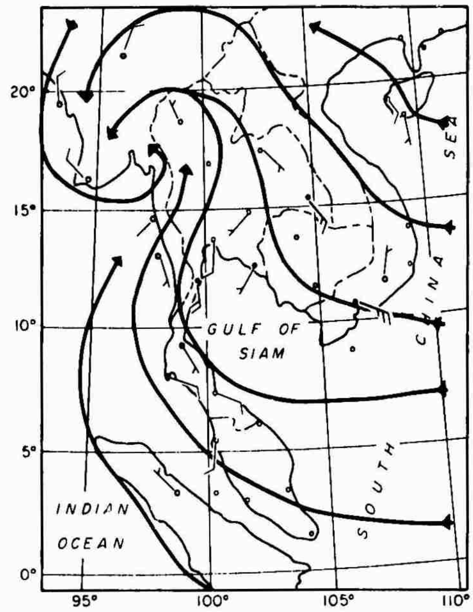

Figure 34.--600-meter streamline analysis at 0000 GMT, 22 March 1963 (analyzed by Thailand Meteorological Department).

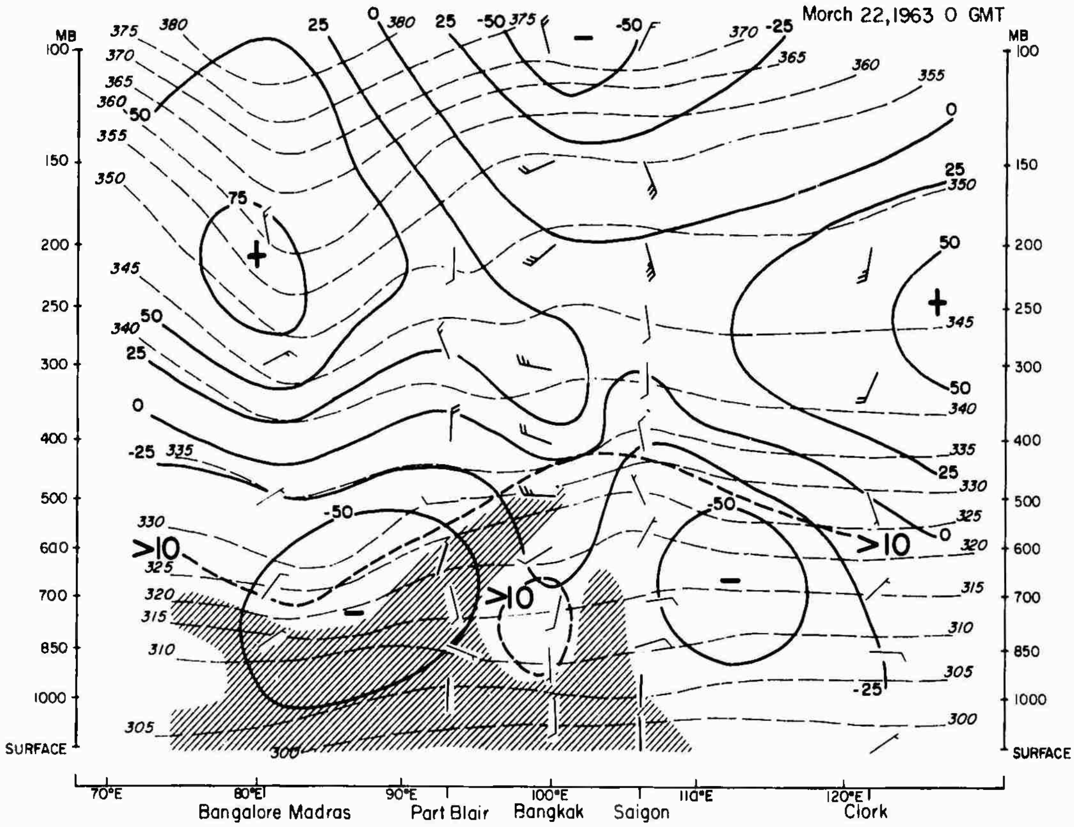

Figure 35.--Vertical space cross-section of "D" Values in meters (solid lines), potential temperature in °K (thin dashed lines), boundary or more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

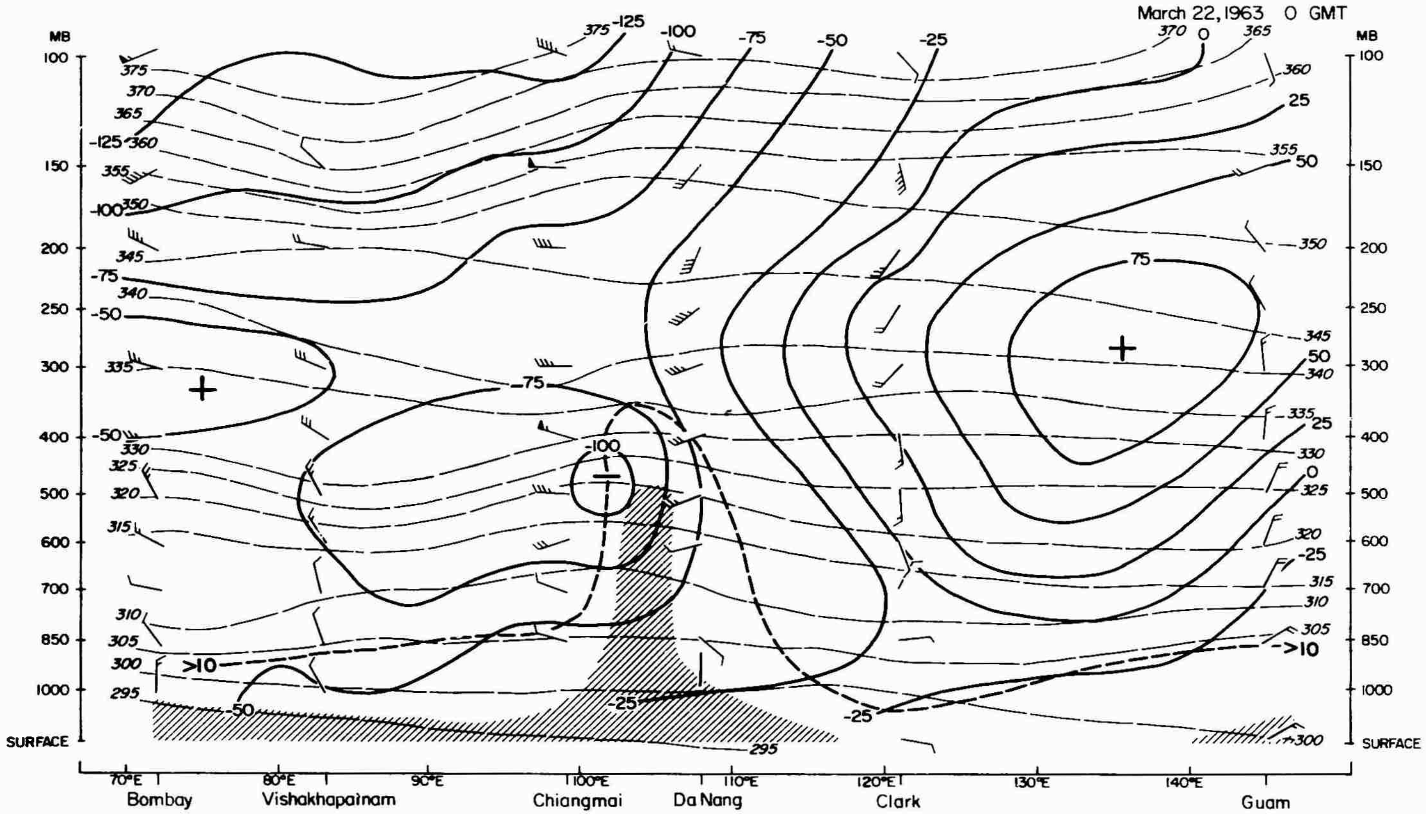

Figure 36.--Vertical space cross-section of "D" Values in meters (solid lines), potential temperature in °K (thin dashed lines), boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

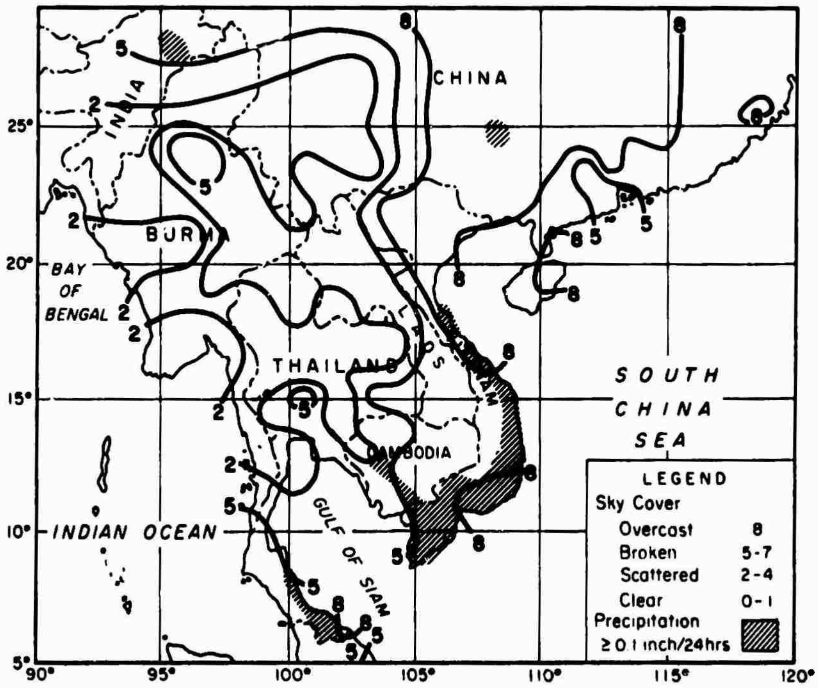

Figure 37.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 24 November 1962.

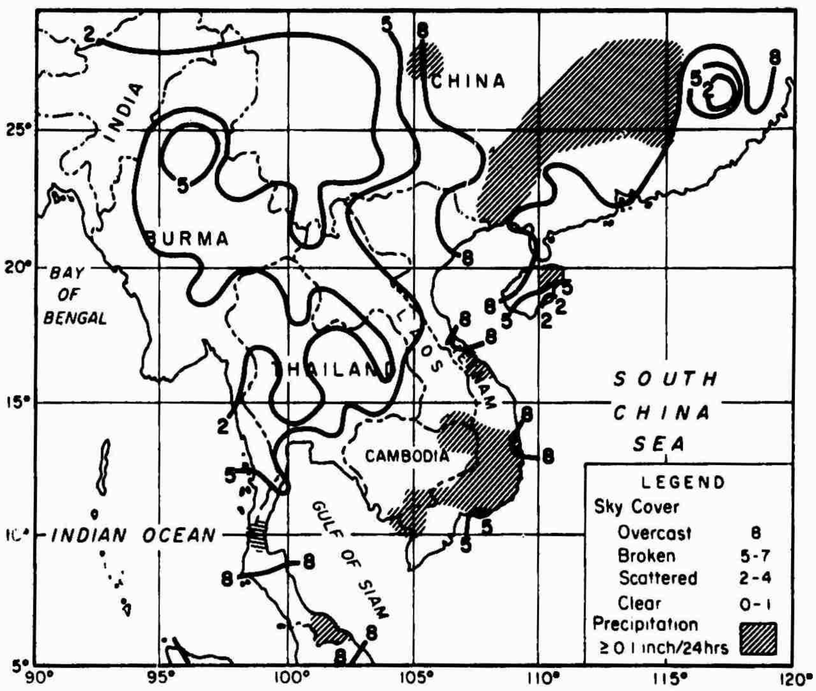

Figure 38.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 25 November 1962.

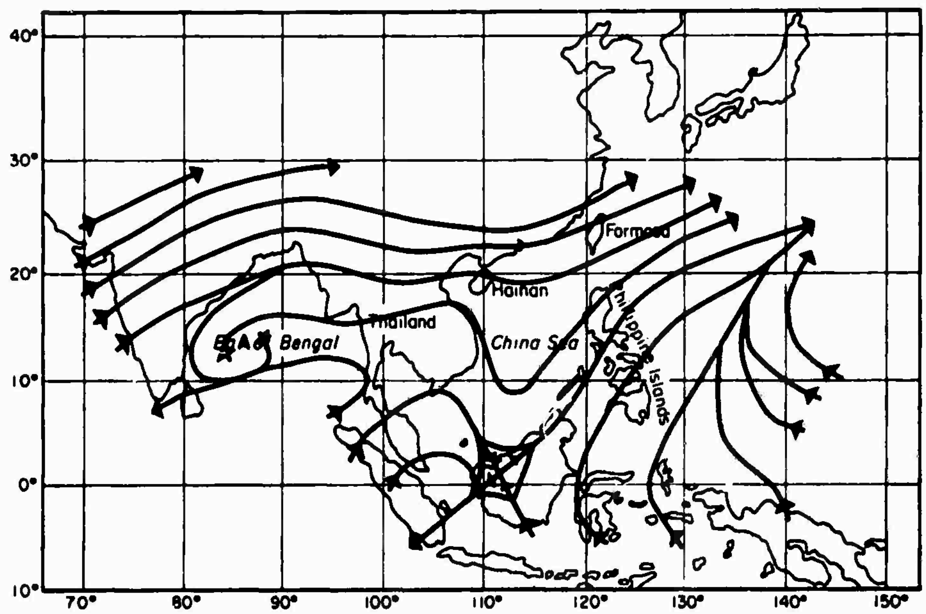

Figure 39.--300 mb. streamline analysis at 0000 GMT, 17 November 1962.

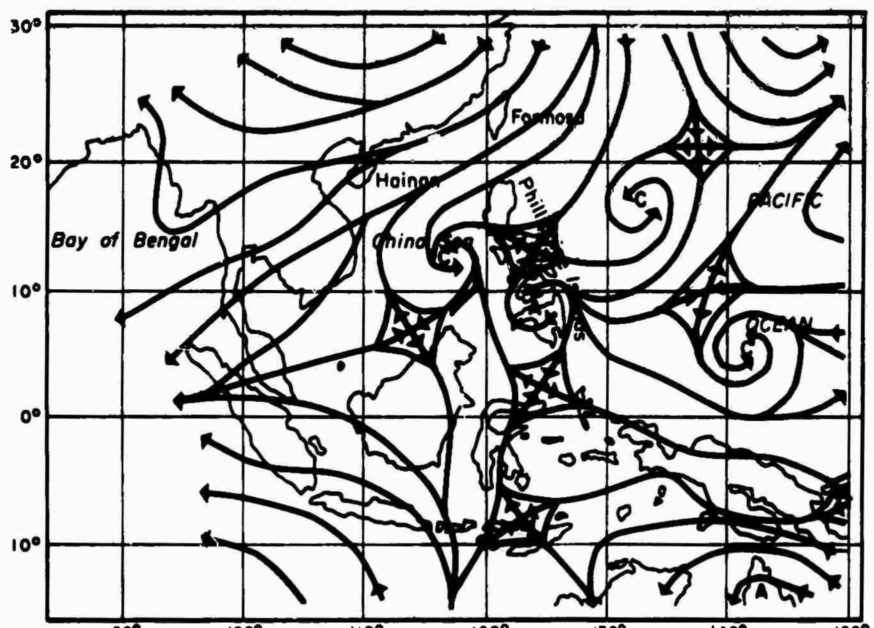

Figure 40.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 0000 GMT, 17 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

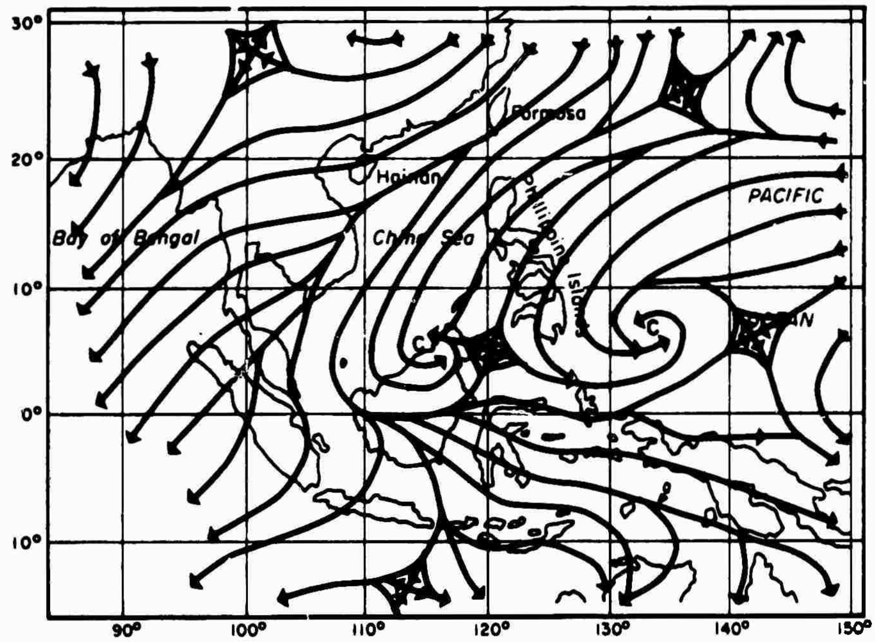

Figure 41.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 0000 GMT, 22 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

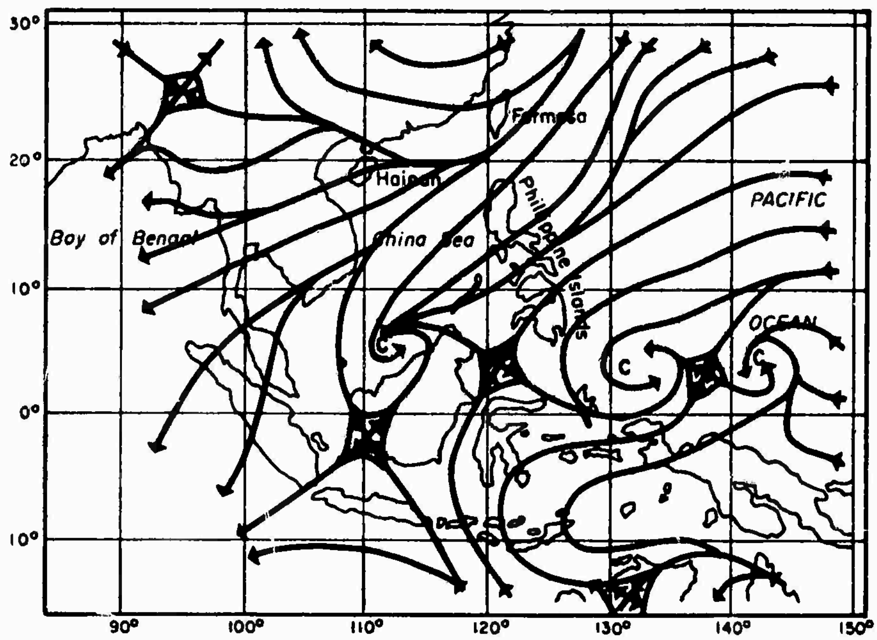

Figure 42.--3,000 ft. (or nearly equal to 900 meters) streamline analysis at 0000 GMT, 24 November 1962. (Analyzed by Detachment 2, 1st Weather Wing, Anderson AFB, Guam.)

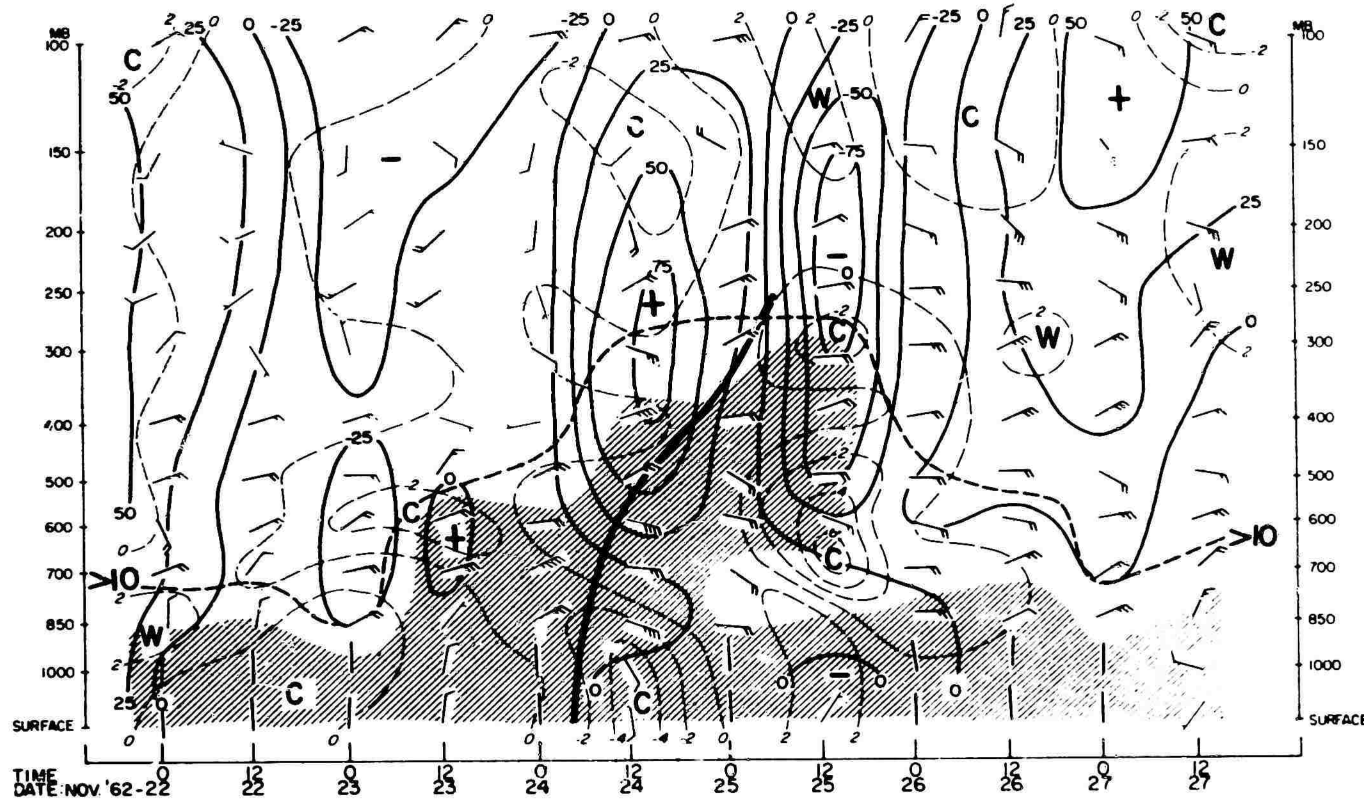

Figure 43.- Vertical time cross-section at Saigon, Vietnam, 22-27 November 1962; shows 24-hour changes in height, in meters (heavy solid lines), and in temperature, in °C (thin dashed lines); and boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C depression (shaded).

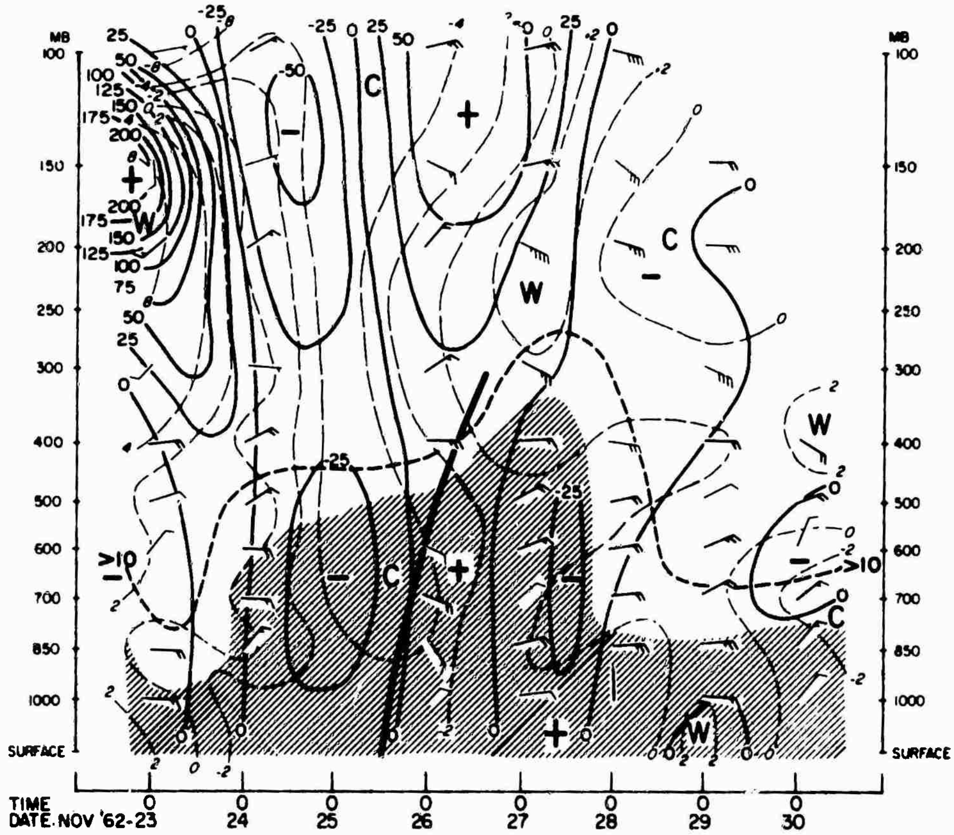

Figure 44.--Vertical time cross-section at Songkhla, Thailand, November 23-30, 1962, shows 24-hour changes in height, in meters (heavy solid lines), and in temperature, in °C (thin dashed lines); and boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C depression (shaded).

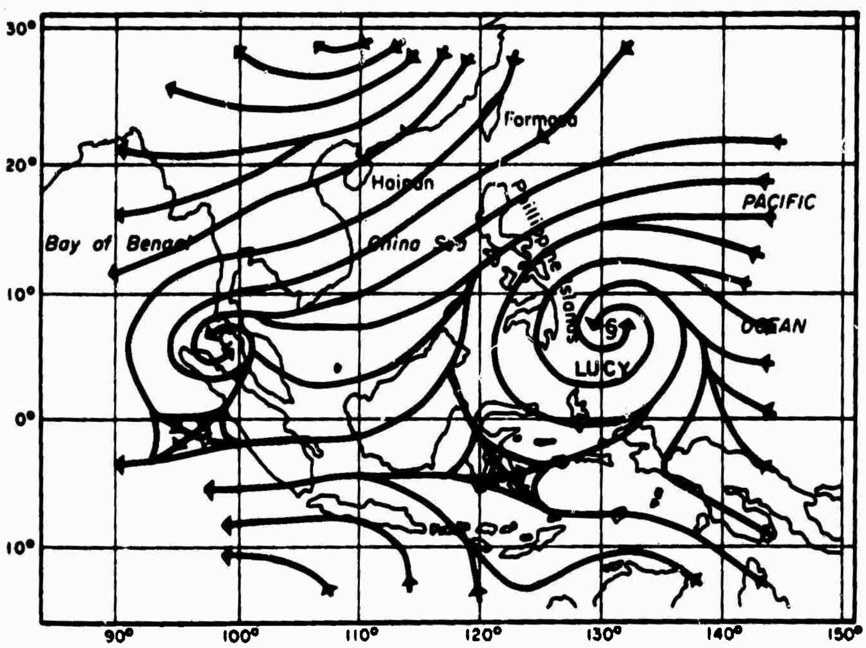

Figure 45.--3,000 ft. (or nearly equal to 900 meter streamline analysis at 0C GMT, 26 November 1962. (Analyzed by Detachment 2 1st Weather Wing, Andersc AFB, Guam.)

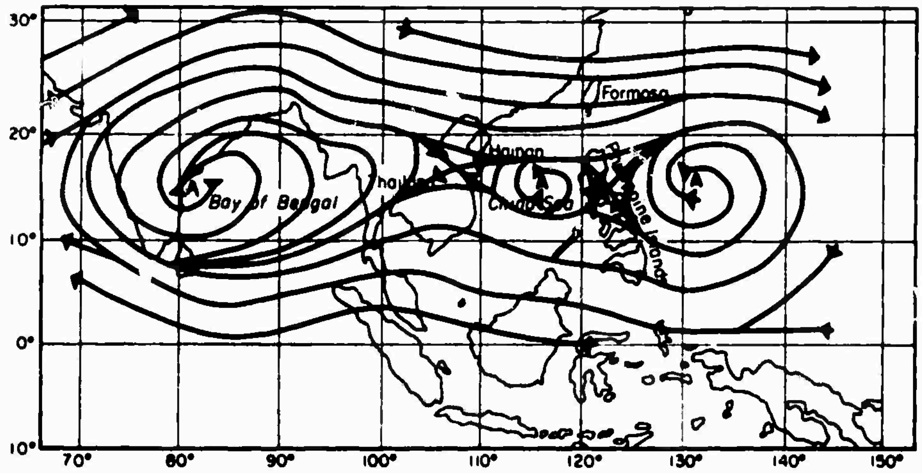

Figure 46.--300 mb. streamline analysis at 0000 GMT, 24 November 1962.

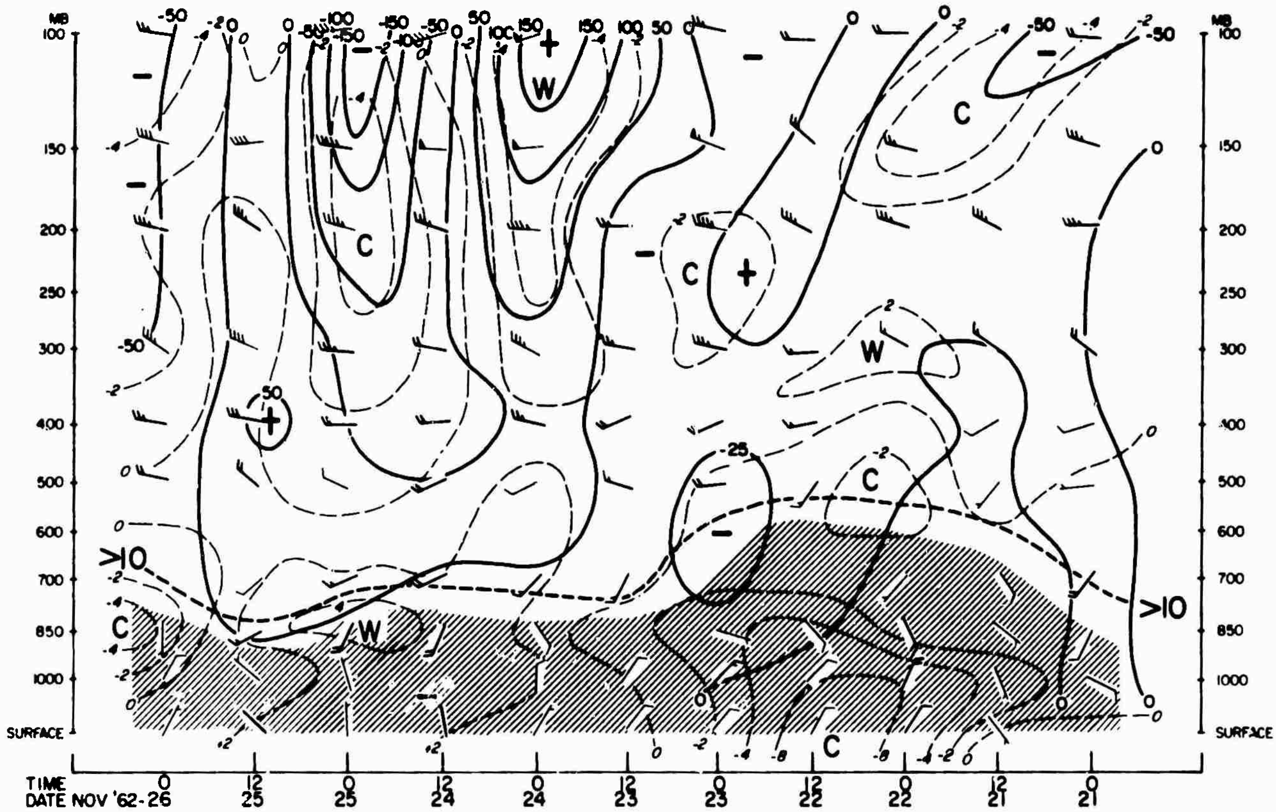

Figure 47.--Vertical time cross-section at Hanoi, North Vietnam, November 21-26, 1962, shows 24-hour changes in height, in meters (heavy solid lines), and in temperature, in °C (thin dashed lines); and boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C depression (shaded).

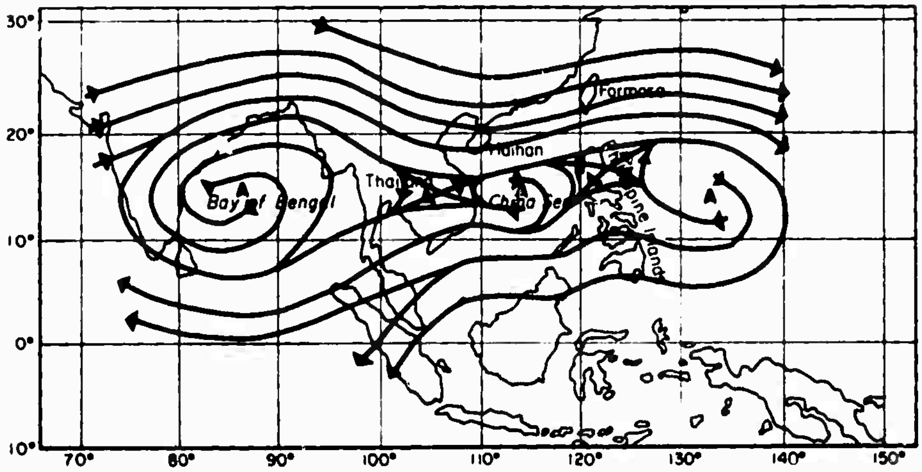

Figure 48.--300 mb. streamline analysis at 0000 GMT, 25 November 1962.

Surge of the Northeast Monsoon

General Rain 29 March 1963

The precipitation and cloud cover maps for 28-30 March 1963 show that only isolated areas of rain fell on the 28th (figs. 49-51). But on 29 March 1963, general rain occurred over western Cambodia, eastern Thailand, northwestern Laos and the mountain areas of northern Thailand (fig. 50). Covering about 120,000 square miles, rainfall was heavy in certain areas. Nakhon Ratchasima, Thailand, for example, received 3.15 inches for the day, and Takeo, Cambodia, 2.31 inches. But, by the 30th the rainfall was restricted to the Gulf of Siam and the coastal areas of Cambodia and South Vietnam (fig. 51).

The movement of the broken and overcast clouds across SEA from the northeast to the southwest from the 28th through the 30th of March was particularly worthy of study. At 0600 G.m.t. on 28 March, broken clouds covered North Vietnam, Laos, the panhandle of northern South Vietnam, and eastern Thailand (fig. 49). By 0600 G.m.t. or the 29th, the broken clouds had pushed westward into Burma and covered most areas south to the Gulf of Siam except for the Annam Mountain area, which had only scattered clouds (fig. 50). On the 30th, clear skies or just scattered clouds covered much of Southeast Asia. Broken clouds, however, were still present along the coastal areas of the Gulf of Siam and in northeastern Burma (fig. 51).

Formation of Inverted Lee Trough

At 0000 G.m.t. on 27 March 1963 a cold front over South China was being pushed south by the large Asian high pressure system (fig. 52). By the 28th, the cold front had pushed south to the border between North Vietnam and South Vietnam (fig. 53). The surge of the northeast monsoon had pushed across SEA and to the southern part of the South China Sea by 0000 G.m.t. on 29 March 1963 (fig. 54). By the

30th, the monsoon was weakening, and the thermal low had appeared again over Burma (fig. 55).

Streamline analyses of the windflow at 600 meters over Southeast Asia for 28 March 1963 at 0000 G.m.t. picture the northeast monsoon moving into North Vietnam. The flow over the rest of the map is indicative of a lull in the northeast monsoon (fig. 56). By 1200 G.m.t. on the 28th, the northeast monsoon had pushed south across South Vietnam, Laos, and eastern Cambodia (fig. 57). The monsoon pushed south much faster, however, along the coast than it did over the Annam Mountains, causing a strong easterly flow across the mountains. And, consequently, an inverted lee trough formed west of the mountain range near 106°E.

Movement of Inverted Lee Trough

As soon as the lee trough formed west of the Annam Mountains it began to move west. The trough became a shallow wave in the easterly flow along the leading edge of the northeast monsoon. By 0000 G.m.t. on 29 March the wave had moved to 103°E. and become a well-defined disturbance (fig. 58), as evidenced by the windflow at 850 mb. (fig. 59). The wave continued to move westward and began to weaken rapidly late on the 29th. By 0000 G.m.t. on 30 March 1963, the wave had dissipated, being no longer visible on the streamline analysis (fig. 60). A small anticyclone had already started to build up over northern Thailand.

Inverted Lee Trough Responsible for Rain

The inverted lee trough that was formed by the northeast monsoon moved westward like an easterly wave across Laos, Cambodia, and Thailand. And, like an easterly wave, the easterly component of the wind near the ground became weaker near the trough line. Therefore, low-level divergence and descending air were found ahead of the trough line and low-level convergence and ascending air to the rear. An anticyclone was located over the area at 700 mb., with divergence at that level (fig. 61). This divergence aloft, coupled with the convergence in the low levels, very likely caused strong ascending motion to the rear of the trough line.

The sounding at Bangkok for 0000 G.m.t., 29 March 1963 shows that the atmosphere over the area was quite unstable, with a lifted index of -2 on the day the wave moved across the area (fig. 62). Likewise, the sounding shows that the moist layer (dewpoint depression of 5°C. or less) extended up to about 3,500 meters.

In addition, a trough in the westerlies moved across Southeast Asia on the 29th and caused 2°C. cooling at 500 mb. This cooling further increased the instability.

Rain on 29 March 1963 fell for the most part to the rear of the lee-trough line as it moved westward across SEA. This rain resulted from the convective activity that occurred to the rear of the trough line; warm moist, unstable air was carried upward by the upward component of motion produced by the low-level convergence and the high-level divergence east of the trough line.

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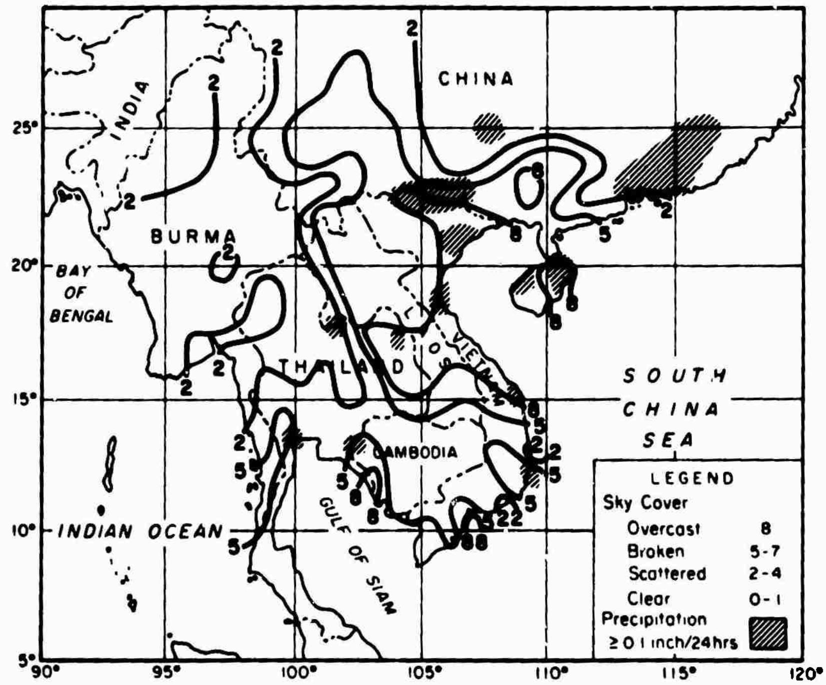


Figure 49.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 28 March 1963.

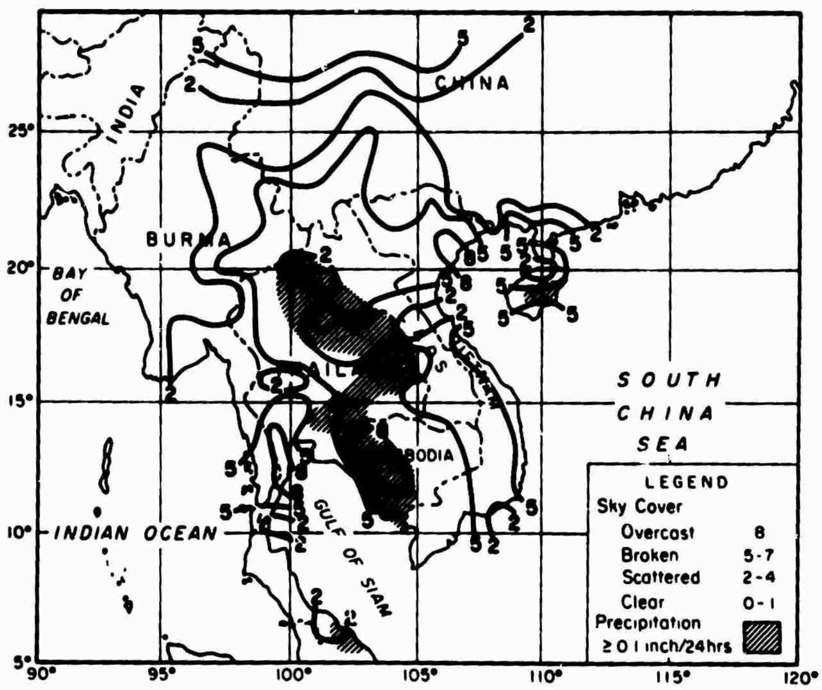


Figure 50.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 29 March 1963.

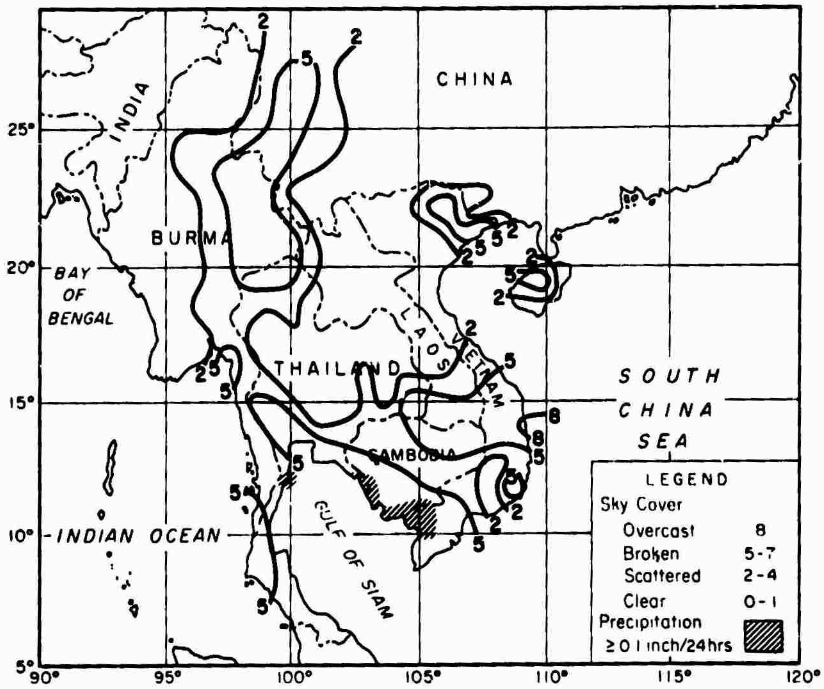


Figure 51.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 30 March 1963.

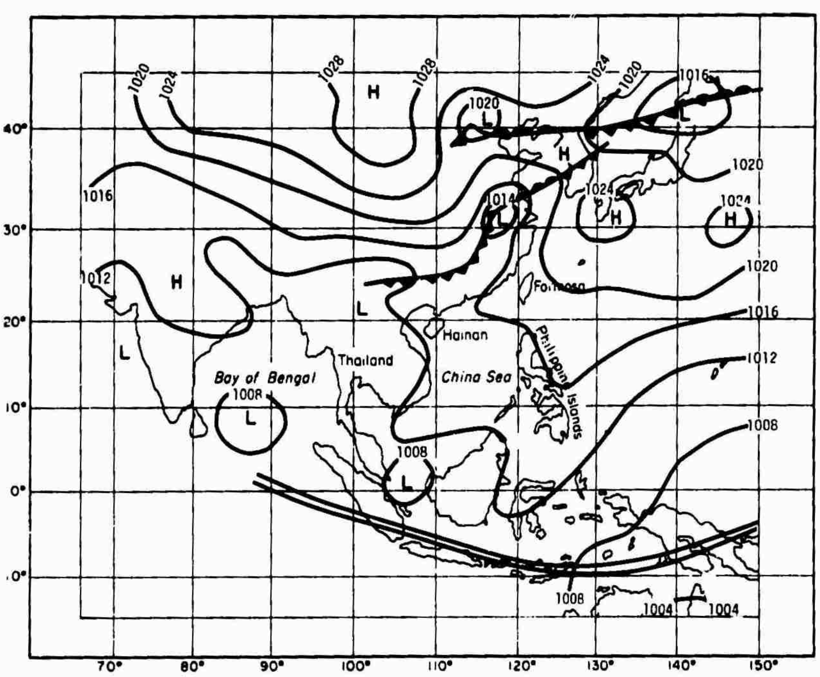


Figure 52.--Surface analysis at 0000 GMT, 27 March 1963 (analyzed by Thailand Meteorological Department).

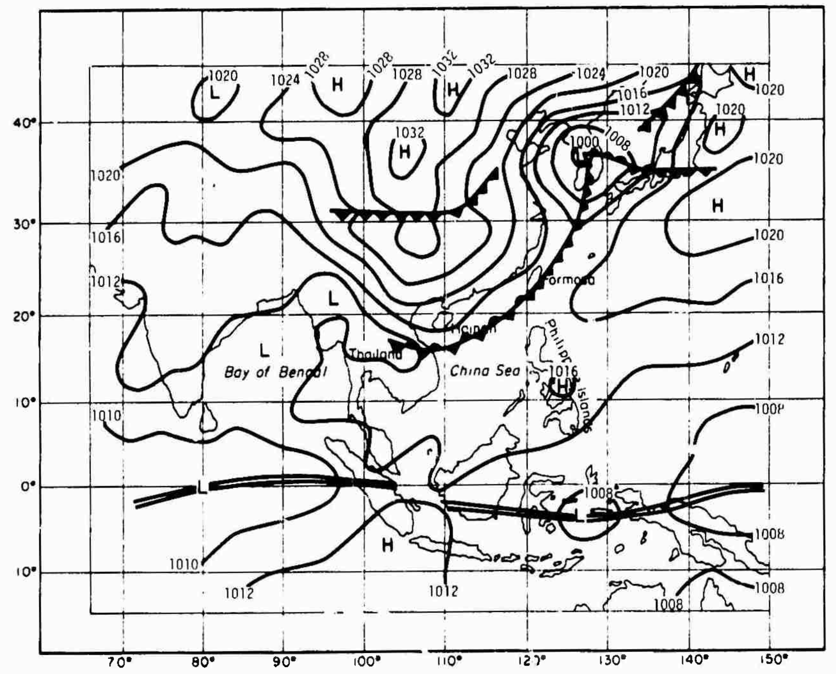


Figure 53.--Surface analysis at 0000 GMT, 28 March 1963. (analyzed by Thailand Meteorological Department).

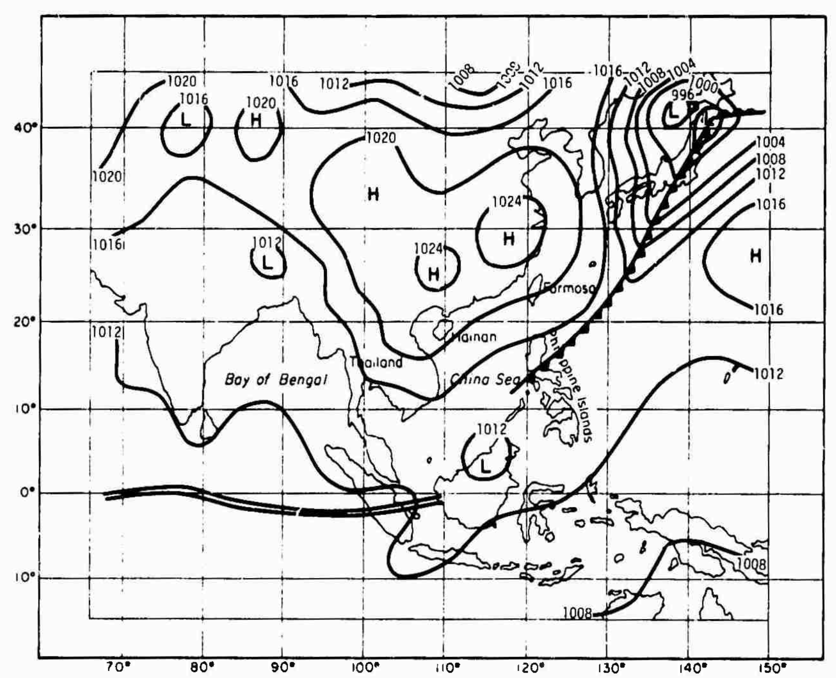


Figure 54.--Surface analysis at 0000 GMT, 29 March 1963 (analyzed by Thailand Meteorological Department).

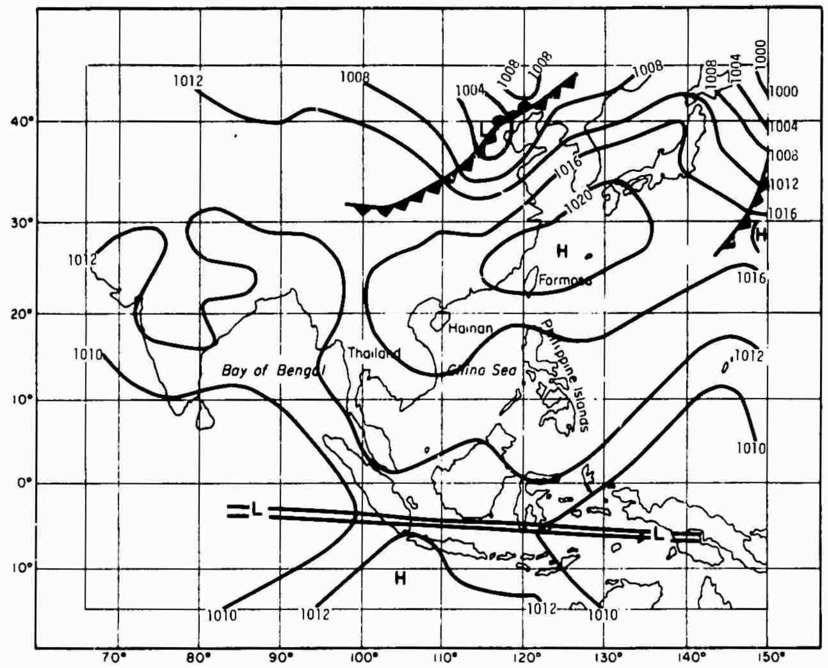


Figure 55.--Surface analysis at 0000 GMT, 30 March 1963 (analyzed by Thailand Meteorological Department).

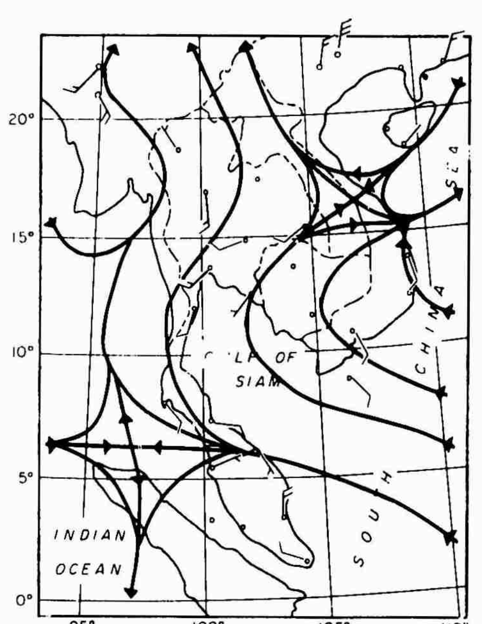


Figure 56.--600-meter streamline analysis at 0000 GMT, 28 March 1963 (analyzed by Thailand Meteorological Department).

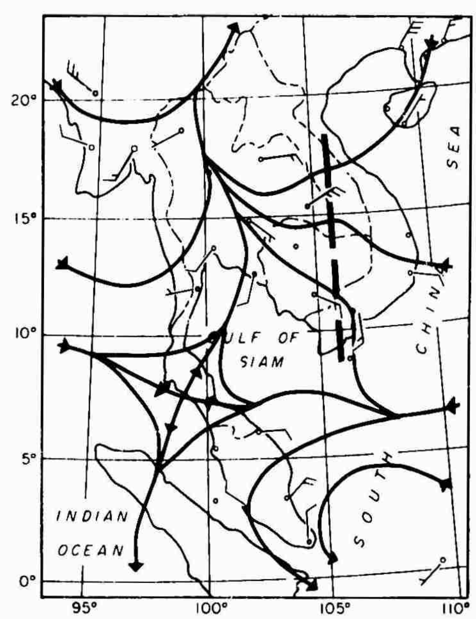


Figure 57.--600-meter streamline analysis at 1200 GMT, 28 March 1963 (analyzed by Thailand Meteorological Department).

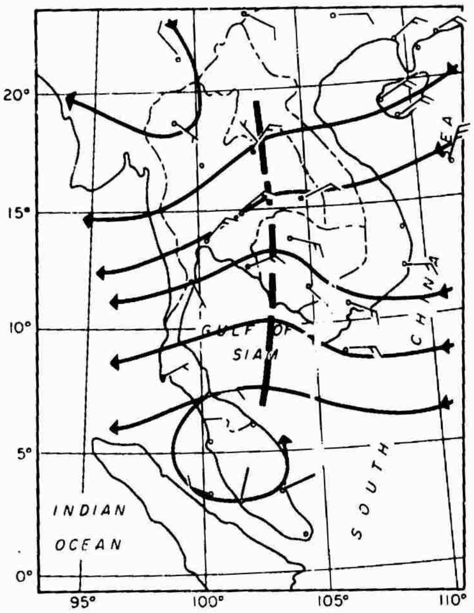


Figure 58.--600-meter streamline analysis at 0000 GMT, 29 March 1963 (analyzed by Thailand Meteorological Department).

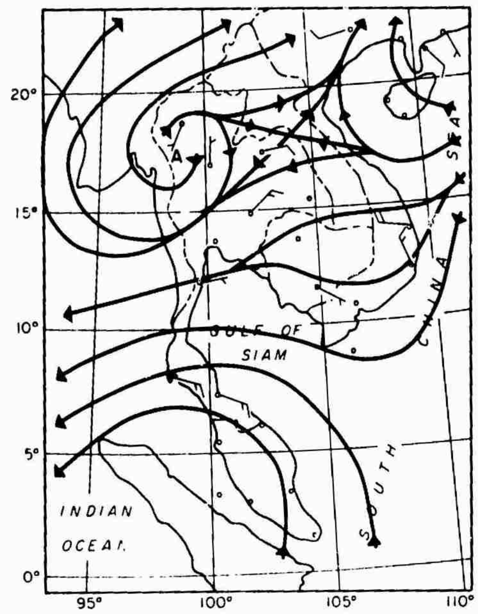


Figure 60.--600-meter streamline analysis at 0000 GMT, 30 March 1963 (analyzed by Thailand Meteorological Department).

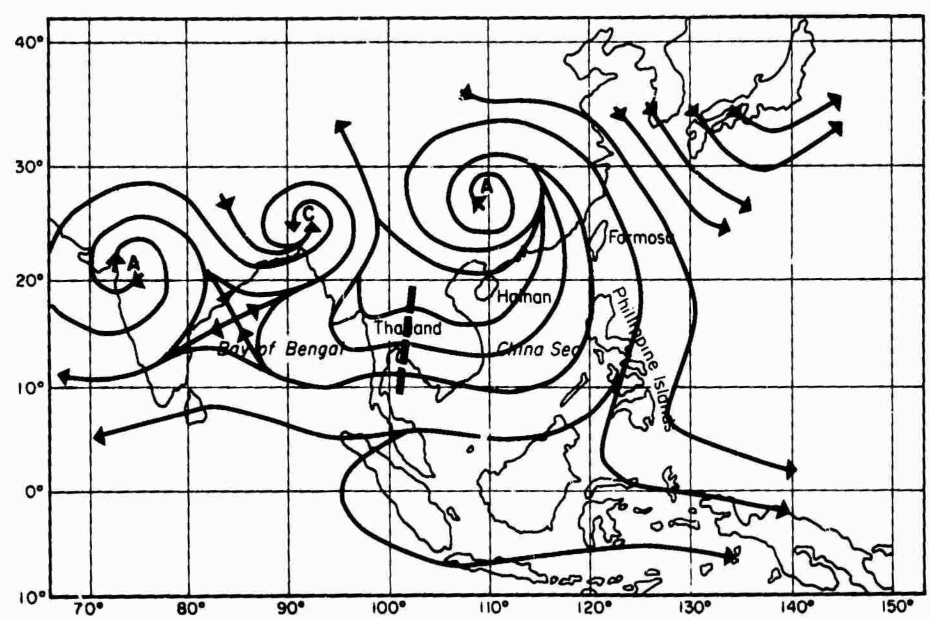


Figure 59.--850 mb. streamline analysis at 0000 GMT, 29 March 1963 (analyzed by Thailand Meteorological Department).

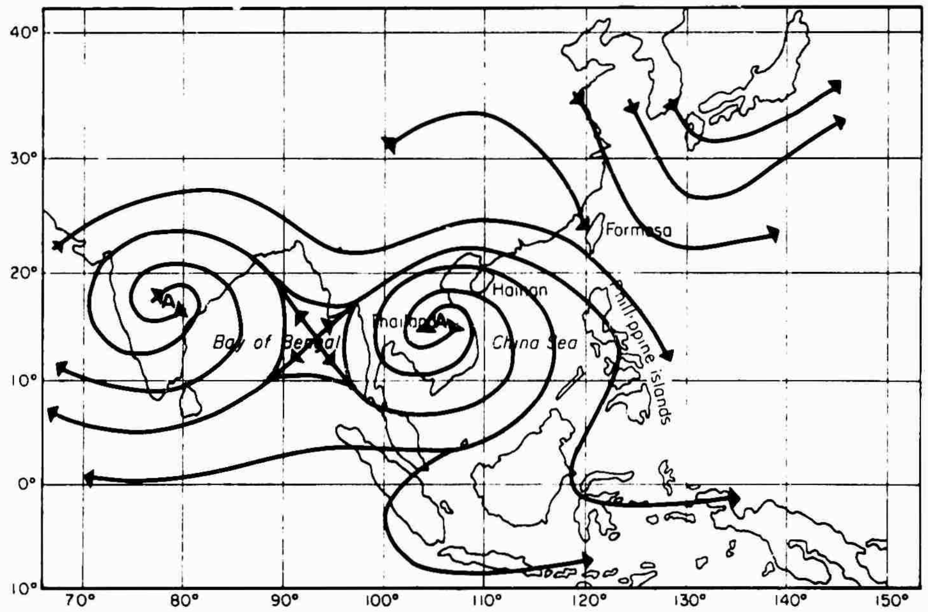
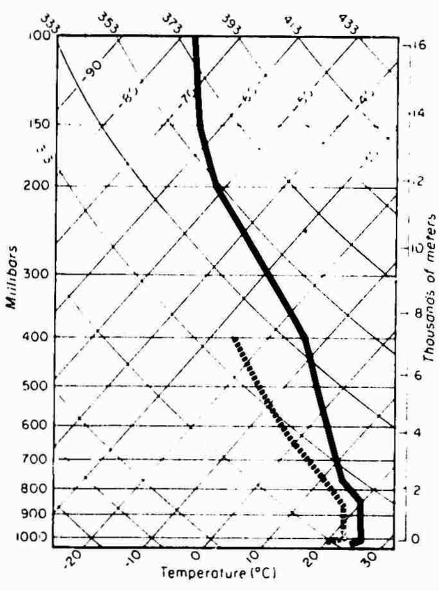


Figure 61.--700 mb. streamline analysis at 0000 GMT, 29 March 1963 (analyzed by Thailand Meteorological Department).

Figure 62.--Skew T, Log P Diagram for Bangkok, Thailand, 0000 GMT, 29 March 1963. Temperatures given by solid line and dewpoint by the dashed line.



This inverted lee trough formed, moved westward like a wave in the easterlies, caused the general rain, and then dissipated. The entire sequence lasted less than 36 hours.

Tropical Trough

General Rain 7-9 March 1963

The precipitation and cloud cover maps show that extensive general rain occurred on 7-9 March 1963 (figs. 63-65). No areas of rain occurred on 5 March and only two small areas show any on the 6th; however, rain on 7 March was so extensive that it covered almost 100,000 square miles. The major rainfall occurred on the 8th when ≥ 0.1 inch rain was recorded over about 225,000 square miles. But by 9 March, the rain area had shrunk to less than 60,000 square miles. And by the 10th rain had moved completely out of the area we studied.

Tropical Trough Responsible for Rain

The surface analysis for 0000 G.m.t., 8 March 1963, shows that the winter monsoon had surged far south, making conditions unfavorable for a tropical cyclone to form (fig. 66). Ramage (1955) reported that in a 50-year period, only three tropical storm days occurred over the China Sea in March. Easterly waves are more common in March than tropical cyclones, but we did not observe any during this rainy period.

If the rain was not caused by a tropical cyclone or an easterly wave, was a tropical trough responsible, as suggested by Ramage (1955)? Ramage described the tropical trough as a deep cold trough in the westerlies, with high-level divergence and low-level convergence ahead of the trough, causing considerable rain. West of the trough line, fine weather and some surface anticyclogenesis occur because of the high-level convergence and low-level divergence. When the trough has become stationary over Thailand and Indochina, the subtropical ridge is displaced 5° latitude south of its normal position.

The 850, 700, and 300 mb. analyses for 0000 G.m.t., 8 March 1963 are characterized by very large anticyclones northeast of the Philippine Islands and off the west coast of India and a deep trough between 90°E. and 100°E. (figs. 67-69). Strong southwest flow across Burma, northern Thailand, and northern Indochina is evident on the 850, 700, and 500 mb. charts. At the 850-mb. level, convergence was found over northern Thailand and northern Indochina. At 300 mb. the trough was located at 100°E., with divergence ahead of the trough. The rain area for 8 March 1963 (fig. 64) extended from the trough line at 300 mb. northeastward over the area of low-level convergence and high-level divergence. To the west of the trough line, only scattered clouds were observed.

The subtropical ridge over Burma, Thailand, and Indochina at 0000 G.m.t., 7 March 1963 was at 19°N. (fig. 70). However, by 0000 G.m.t. on the 8th the ridge was displaced south to 14°N. (fig. 71).

Vertical space cross-sections for 0000 G.m.t., 8 March 1963, were analyzed both along east-west and north-south axes (figs. 72-75). They provide a three-dimensional view of the atmosphere over Southeast Asia. The Bangalore-Clark cross-section (fig. 72) displays a deep, broad trough separating two large high pressure areas. Cold air in the trough is shown by the dome of potential temperatures above Port Blair. The cold air is most pronounced above 500 mb. and overrides a deep, moist layer. In the cross-section between Bombay and Guam (fig. 73), the trough extends almost to the surface, and its deepness is evidenced by the more than 200-meter height difference between it and the ridge at 135°E. The potential temperatures show that cold air is found above 400 mb. ahead of the trough line. Along the transect of this cross-section, rain occurred ahead of the trough line and fair weather behind the trough line.

The north south cross-section (fig. 74) has the deep trough to the north and the equatorial trough to the south separated by the subtropical ridge. The ridge slopes sharply to the south with height, allowing the trough to push much farther south at high levels than it did at lower levels. The strong vertical gradient of potential temperatures above Gauhati, Chaingmai and Bangkok suggest that the tropopause is at 250 mb. above Gauhati, and 125 mb. above Chaingmai and Bangkok. The Subtropical Jet Stream is over Gauhati at about 150 mb. (fig. 75); this probably means that the tropopause break is at this point (Reiter 1963).

From the facts about the tropical trough given by Ramage and the information we have for this synoptic-scale disturbance, it is quite evident that this disturbance is what Ramage calls a "tropical trough."

Origin of the Tropical Trough

A trough moving east along the Mediterranean Coast of North Africa was first observed in our analysis at 0000 G.m.t., 28 February 1963 over the Nile River in Egypt (fig. 76). A large anticyclone was centered over Aden, and as the trough continued to move east the anticyclone moved to the northwest. These movements allowed the trough to dig to the south and deepen when it reached 60°E. on 2 March 1963 (Fig. 77). This trough then moved over the Arabian Sea and deepened to become a "tropical trough." Therefore, the only difference between a tropical trough and a trough in the westerlies is one of degree. Generally, a trough in the westerlies--like the one that deepened here on 15 March 1963 (fig. 27)--is not as deep nor cold.

Movement of the Tropical Trough

After the trough deepened and became a tropical trough it continued its eastward movement, and at the 300-mb. level it passed Bombay at about 0600 G.m.t. on 3 March (fig. 78). The trough is indicated by the zero height change line where height had just fallen then risen. The zero line passed Bombay at 300 mb. at 1800 G.m.t. on the 3rd; therefore, the trough passed about 0600 G.m.t. The trough was followed by a sharp veering of the wind but no moist layer was evident. By the 5th, the trough was over eastern India (fig. 79) and passed Port Blair about 1800 G.m.t. on the 5th (fig.

80). The moist layer extended to 500 mb. ahead of the trough at Port Blair, but no precipitation occurred. The trough was over the Bay of Bengal on the 6th (fig. 81), but the lower portion of the trough moved faster than the upper portion. Therefore, the trough at the 300-mb. level did not pass Calcutta until around 0600 G.m.t. on the 6th (fig. 82). When the trough passed Calcutta, its temperature rose by 14°C. and its height by 400 meters, indicating the strength of the ridge behind the trough.

The trough, with general rain occurring ahead of it, moved to central Burma on the 7th (fig. 83). The Skew T, Log P diagram for 0000 G.m.t. on the 7th for Bangkok shows effects of the approaching trough with less than 5°C. dewpoint depression through 700 mb. (fig. 84). The Showalter Index was +1 and the Lifted Index -4. Light precipitation occurred in the vicinity on the 7th.

By the 8th, the moist layer over Bangkok had risen to above 600 mb., the Showalter Index had dropped to zero and the Lifted Index had gone to -5 (fig. 85). The trough moved into Thailand on the 8th (fig. 86) and passed Bangkok shortly after 0000 G.m.t. on the 8th with a veering of the wind and a sharp drop in the moist layer (fig. 87). In addition, the west winds lowered down to the 500 and 600 mb. levels after the trough passage. The trough was still moving eastward on the 8th, but had not affected Saigon by 0000 G.m.t., on the 8th (fig. 88). The Showalter Index was +6 and little moisture was present.

By 0600 G.m.t. the trough had passed Saigon with a moist layer extending to 600 mb. immediately ahead of the trough (fig. 89). The Skew T, Log P diagram for 0000 G.m.t. on the 9th shows that considerable moisture remained at Saigon after the trough passed (fig. 90). In fact, Saigon received 0.31 inch of rain on the 9th. The Showalter Index on the 9th was +2 compared with +6 the day before. The trough weakened on the 9th, but continued to move slowly eastward (fig. 91). It passed Hanoi at about 0600 G.m.t. on the 9th (fig. 92). But on the 8th, before the trough passed, a deep, moist layer had extended above 300 mb. over Hanoi and light rain fell during the day. Figure 93 shows a Showalter Index of +2 for the 8th. The air had started to dry out before the trough passed Hanoi, yet traces of rain occurred both on the 9th and 10th.

Dissipation of the Tropical Trough

The trough moved east of Hanoi by 0000 G.m.t. on the 10th (fig. 94), but then appears to have retrograded to the west of Hanoi by 0000 G.m.t. on the 11th and dissipated (fig. 95).

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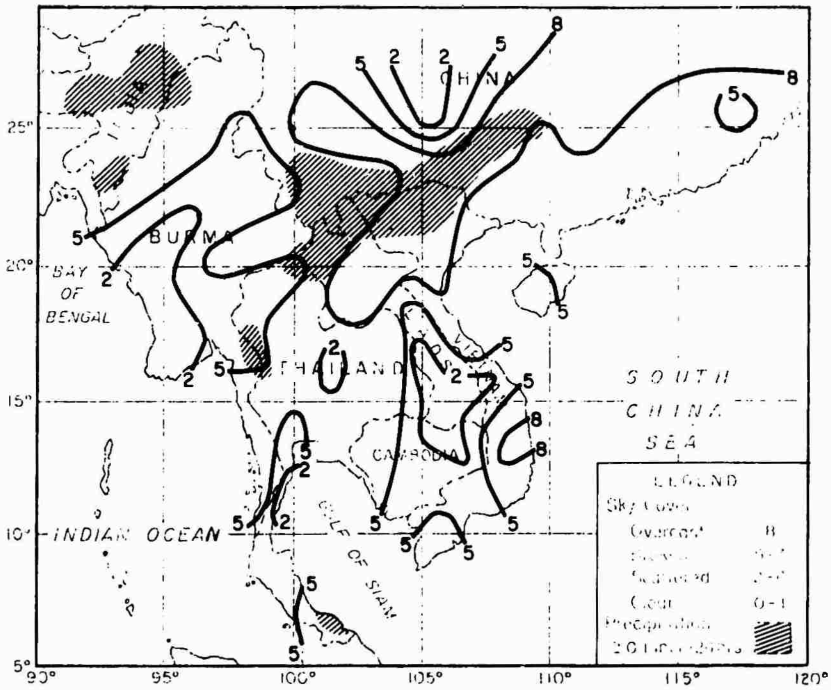

Figure 63.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 7 March 1963.

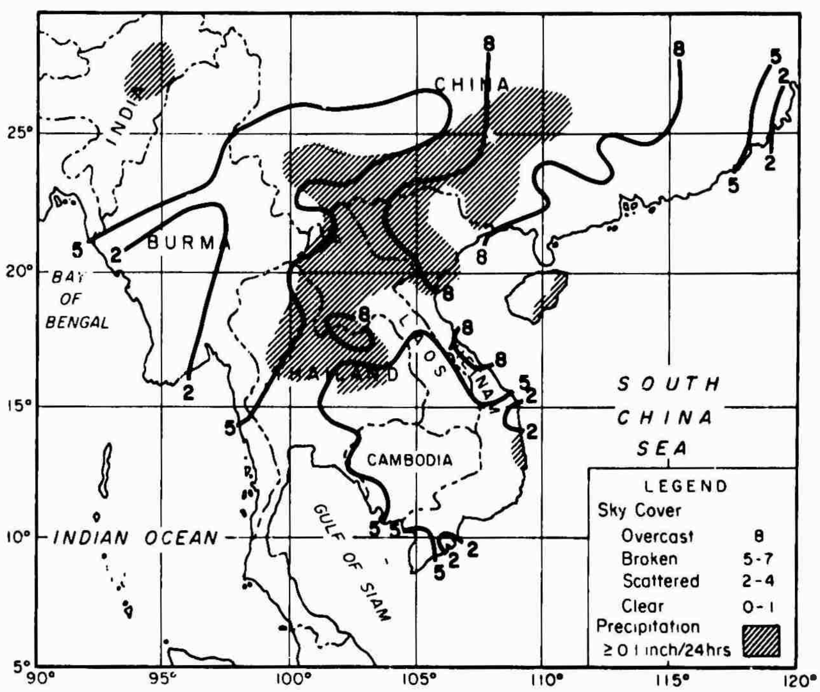

Figure 64.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 8 March 1963.

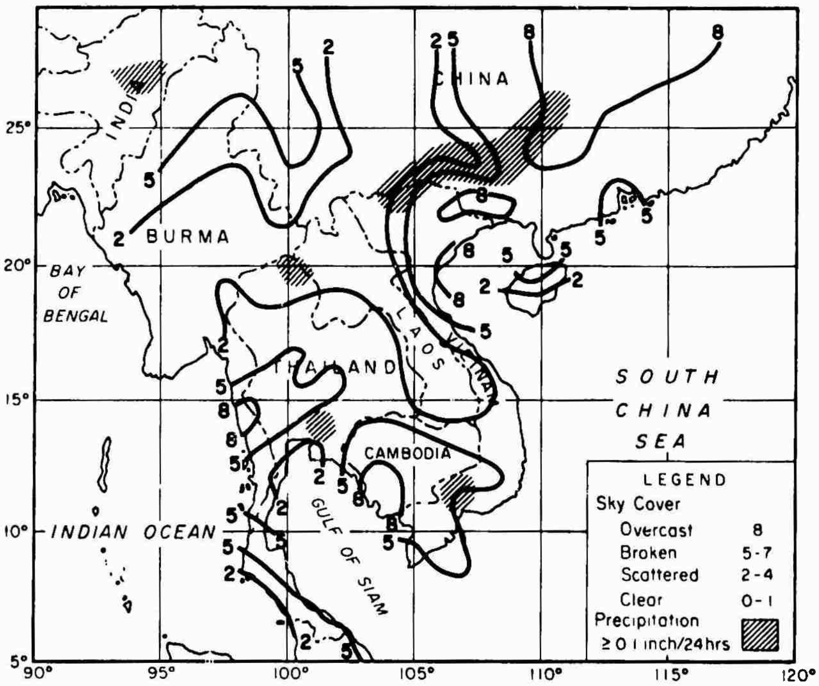

Figure 65.--Analysis of 24-hour precipitation and 0600 GMT total cloud cover for 9 March 1963.

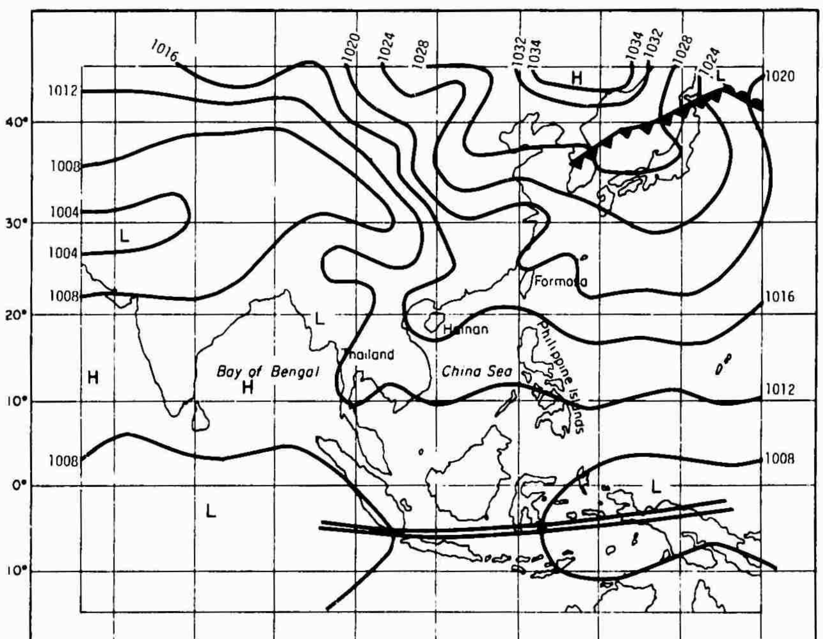

Figure 66.--Surface analysis at 0000 GMT, 8 March 1963 (analyzed by Thailand Meteorological Department).

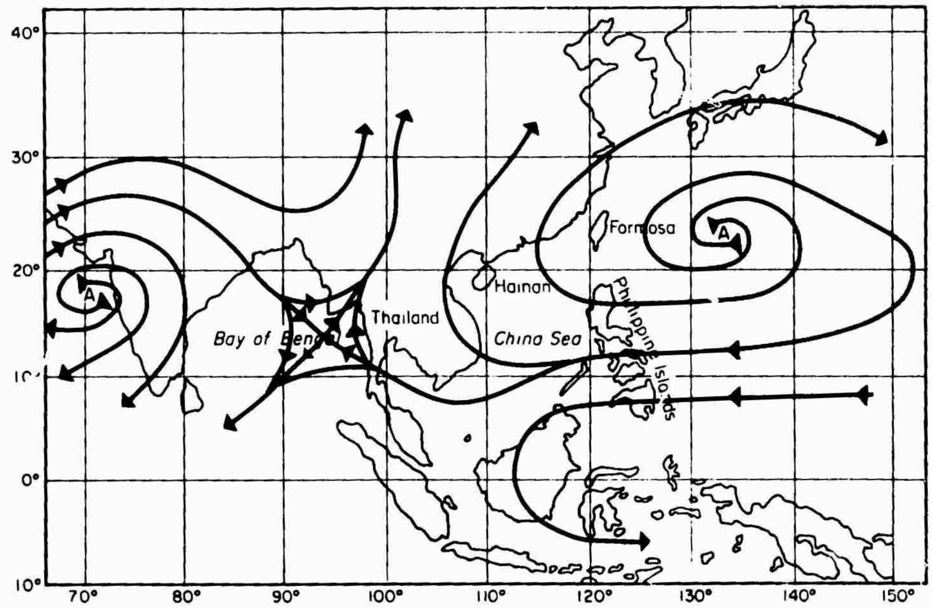

Figure 67.--850 mb. streamline analysis at 0000 GMT, 8 March 1963 (analyzed by Thailand Meteorological Department).

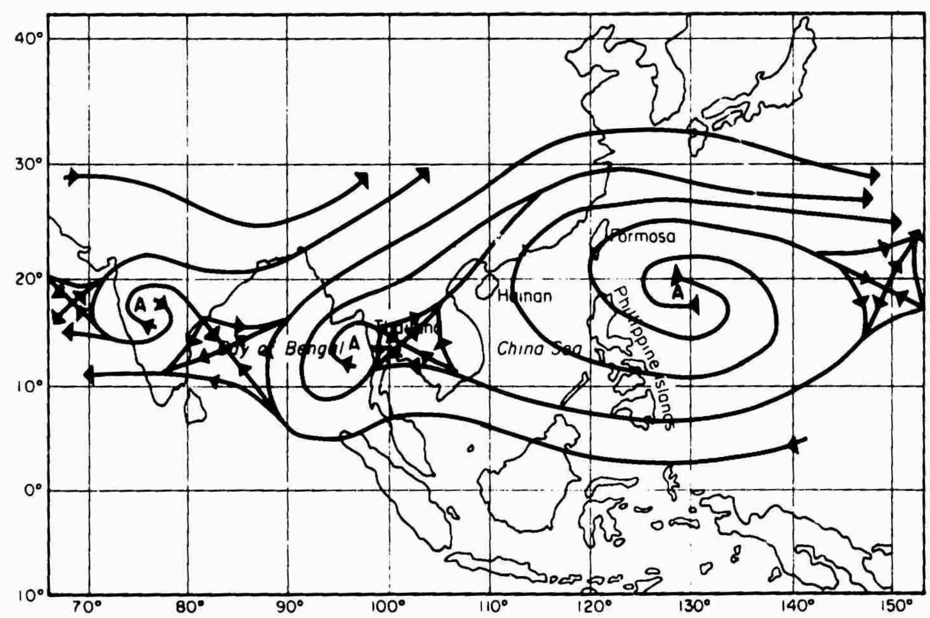

Figure 68.--700 mb. streamline analysis at 0000 GMT, 8 March 1963 (analyzed by Thailand Meteorological Department).

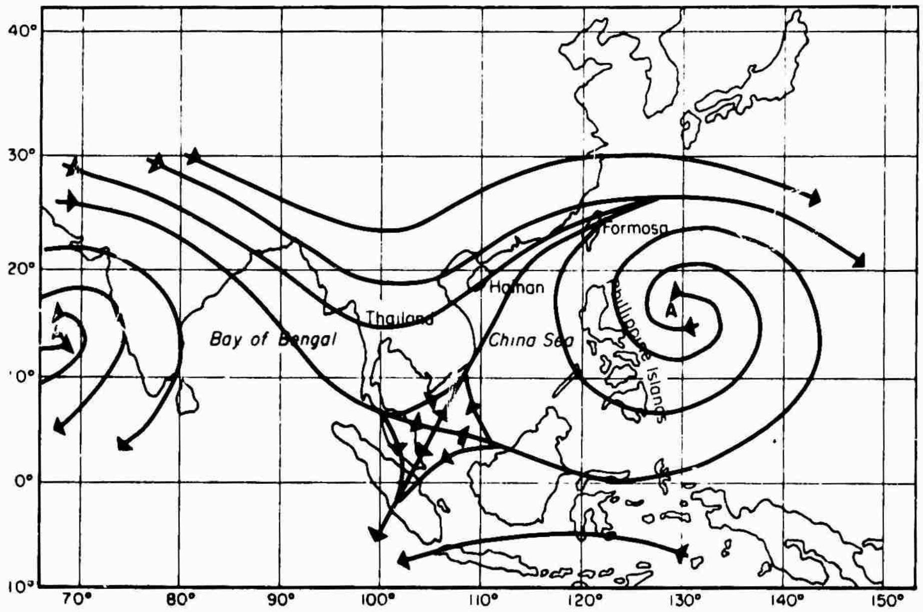

Figure 69.--300 mb. streamline analysis at 0000 GMT, 8 March 1963 (analyzed by Thailand Meteorological Department).

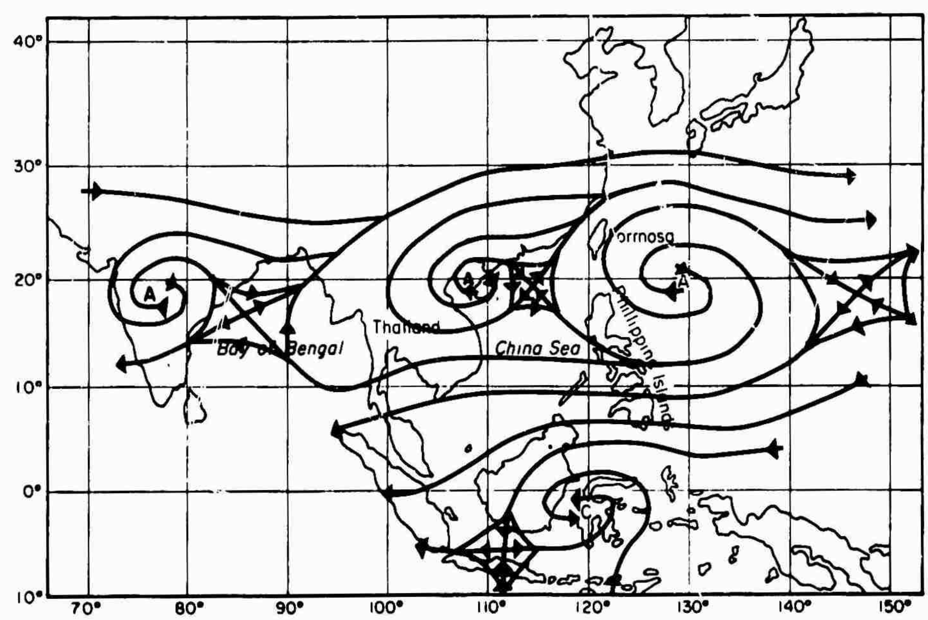

Figure 70.--700 mb. streamline analysis at 0000 GMT, 7 March 1963 (analyzed by Thailand Meteorological Department).

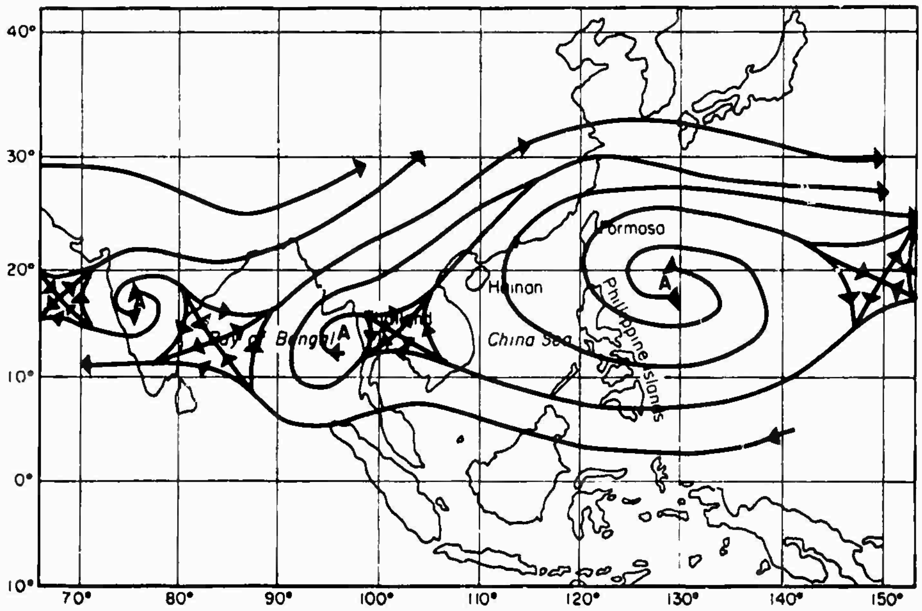

Figure 71.--700 mb. streamline analysis at 0000 GMT, 8 March 1963 (analyzed by Thailand Meteorological Department).

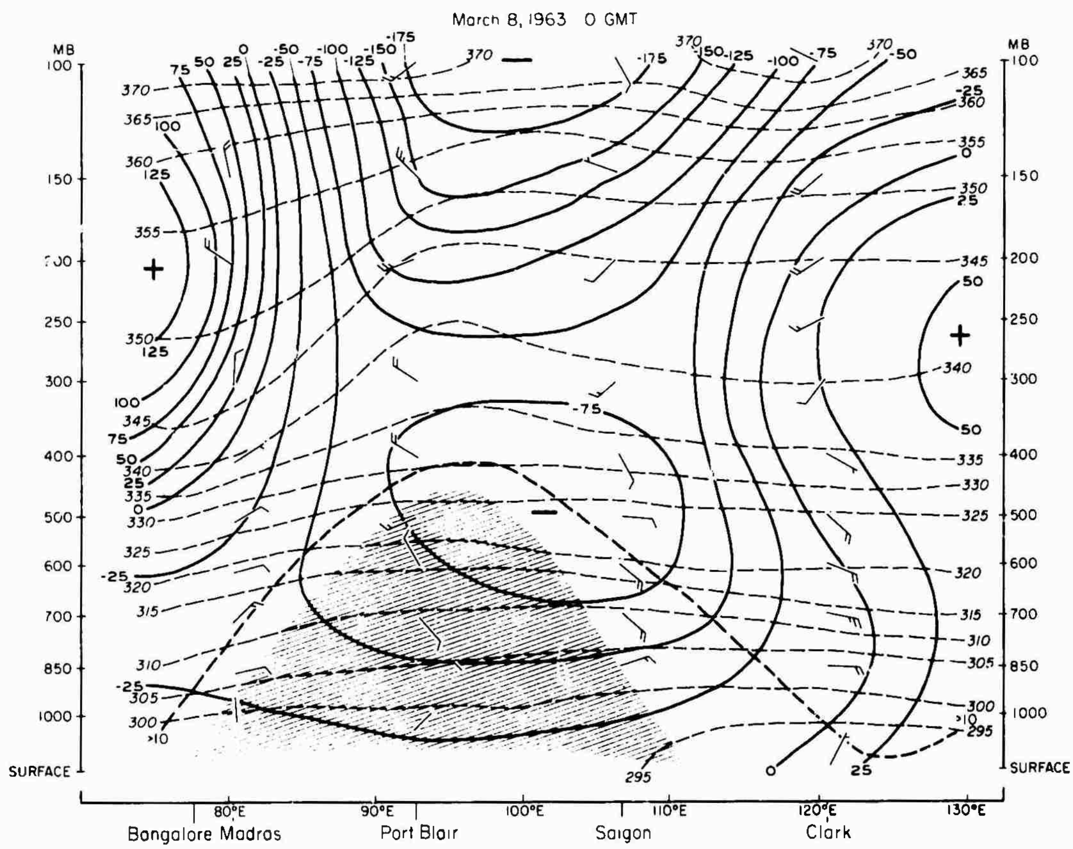

Figure 72.--Vertical space cross-section of "D" Values in meters (solid lines), potential temperature in °K (thin dashed lines), boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

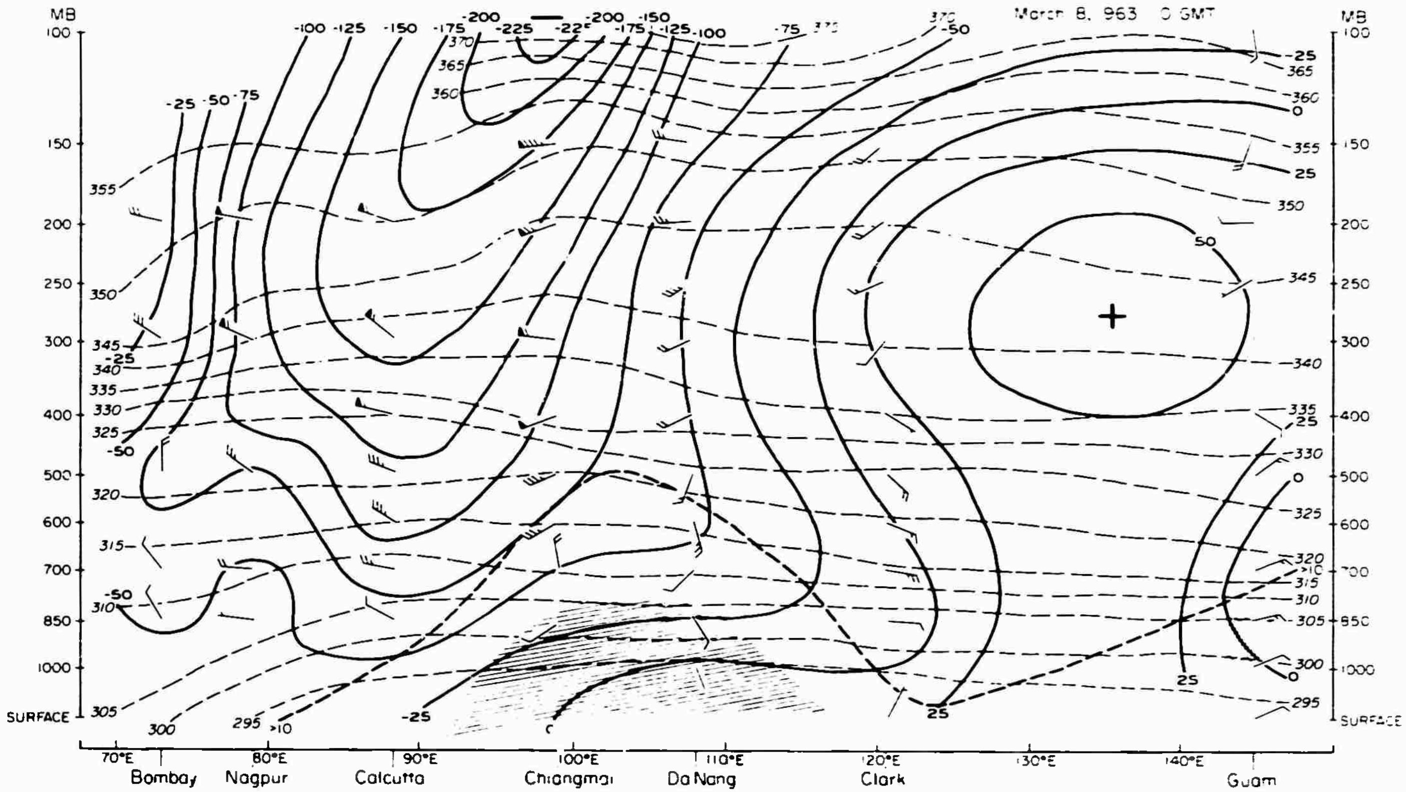

Figure 73.--Vertical space cross-section of "D" Values in meters (solid lines), potential temperature in °K (thin dashed lines), boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

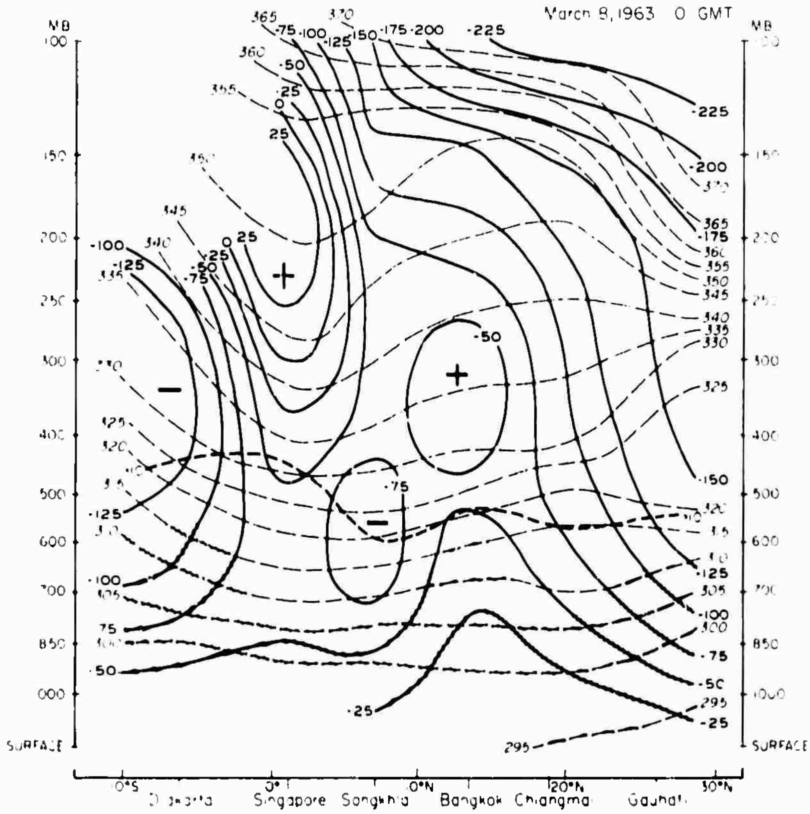

Figure 74.--Vertical space cross-section of "D" Values in meters (solid lines), potential temperature in °K (thin dashed lines), boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

SUMMARY

Because fire climate in Southeast Asia is affected by two major factors, rainfall and cloud cover, we investigated the causes of extensive rainfall over a 5-year period. We found five main types of snyoptic-scale weather disturbances that produce rain during the normally dry period, November through April, by using the techniques of synoptic climatology to relate each period of general rain to its cause. These synoptic-scale disturbances were: (1) Tropical cyclones and easterly waves, (2) troughs in the westerlies, (3) superposition of troughs in the westerlies on easterly waves, (4) surges of the northeast monsoon, and (5) tropical troughs.

Many periods of general rain during the dry periods from November 1959 through April 1964 were found. Five case histories, from the dry period November 1962 through April 1964, were selected for this report as examples of each of the five types of weather disturbances:

1. Typhoon Lucy moved from the China Sea across the southern tip of South Vietnam on 30 November 1962 and caused moderate to heavy rainfall over much of southern South Vietnam.

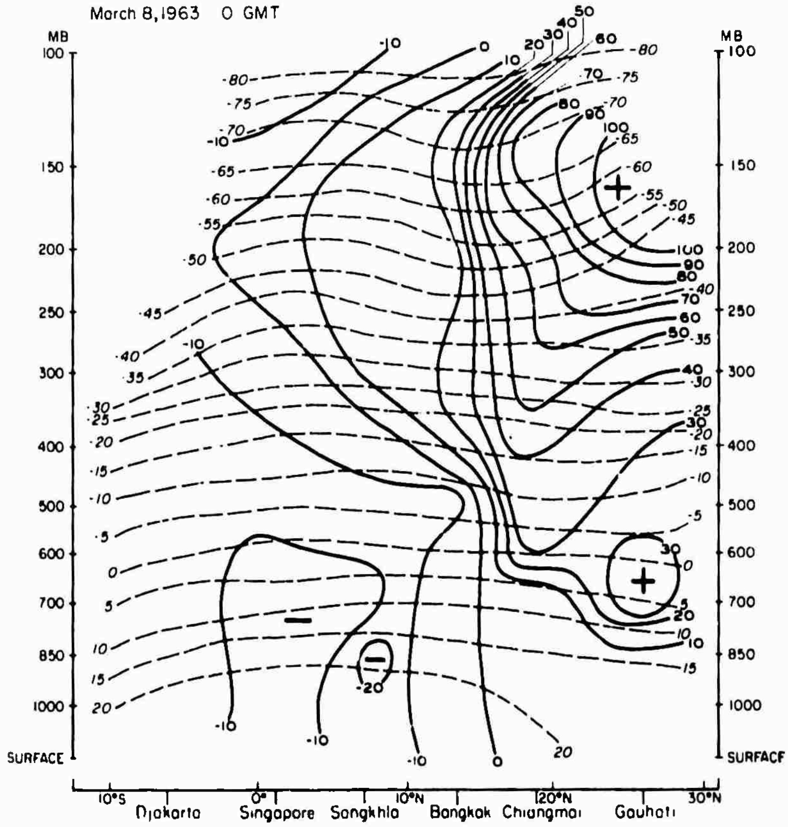

Figure 75.--Vertical space cross-section of east-west wind component in knots (solid line) where positive indicates west component and negative east, and temperature in °C (dashed line).

2. A trough in the westerlies moved eastward from northern India and deepened over Southeast Asia. Low-level convergence and high-level divergence occurred ahead of the trough and caused considerable rain on 21-23 March 1963.

3. An easterly wave caused general rain over a wide area in Southeast Asia on 24 and 25 November 1962. In this case, however, superposition of a trough in the westerlies on the easterly wave intensified both and probably caused more rain than would have occurred from the easterly wave alone.

4. As a surge of the northeast monsoon pushed over the Annam Mountains, a lee trough formed and moved westward like an easterly wave. General rain occurred on 29 March 1963 as the trough moved westward across Southeast Asia.

5. A "tropical trough" formed in the Arabian Sea, moved eastward to Southeast Asia, and deepened. Strong low-level convergence and high-level divergence occurred ahead of the trough and large areas of rain occurred on 7-9 March 1963.

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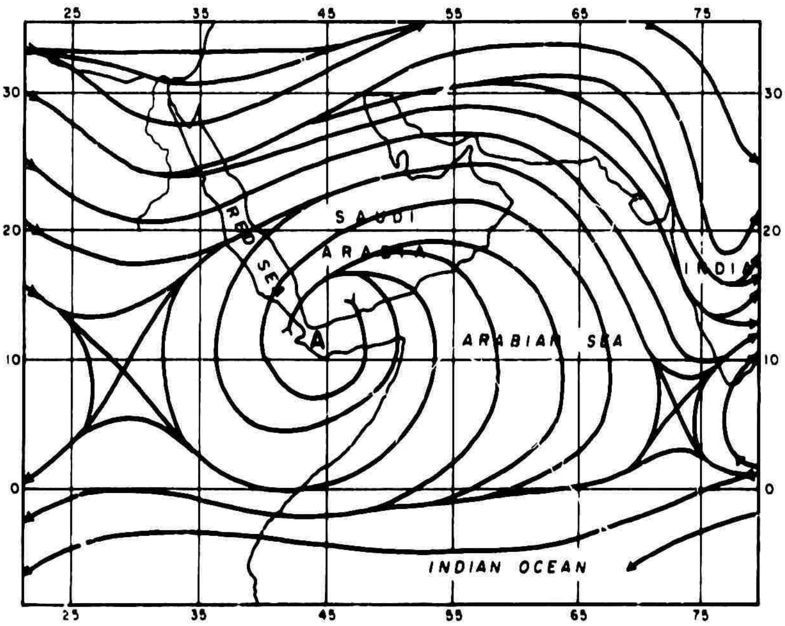


Figure 76.--300 mb. streamline analysis at 0000 GMT, 28 February 1963. (Analyzed by Indian Meteorological Centre, Bombay, India.)

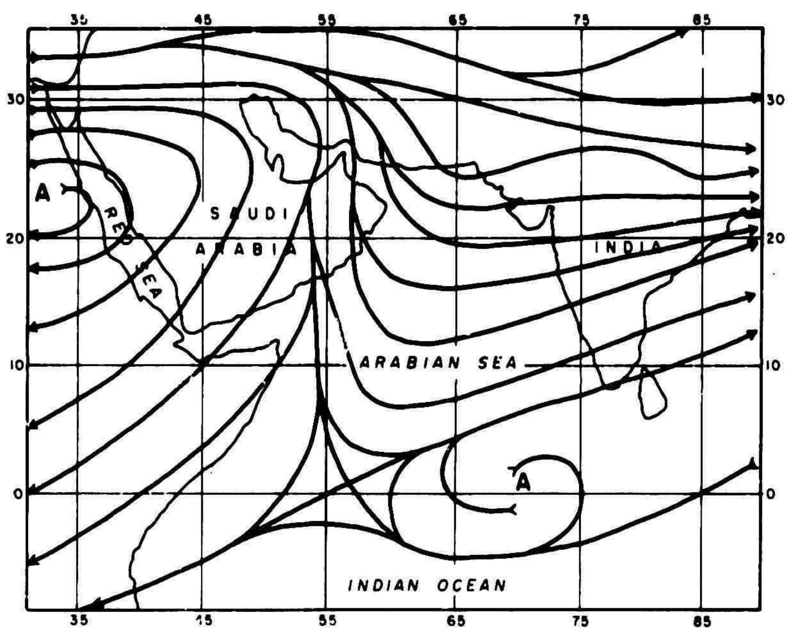


Figure 77.--300 mb. streamline analysis at 0000 GMT, 2 March 1963. (Analyzed by Indian Meteorological Centre, Bombay, India.)

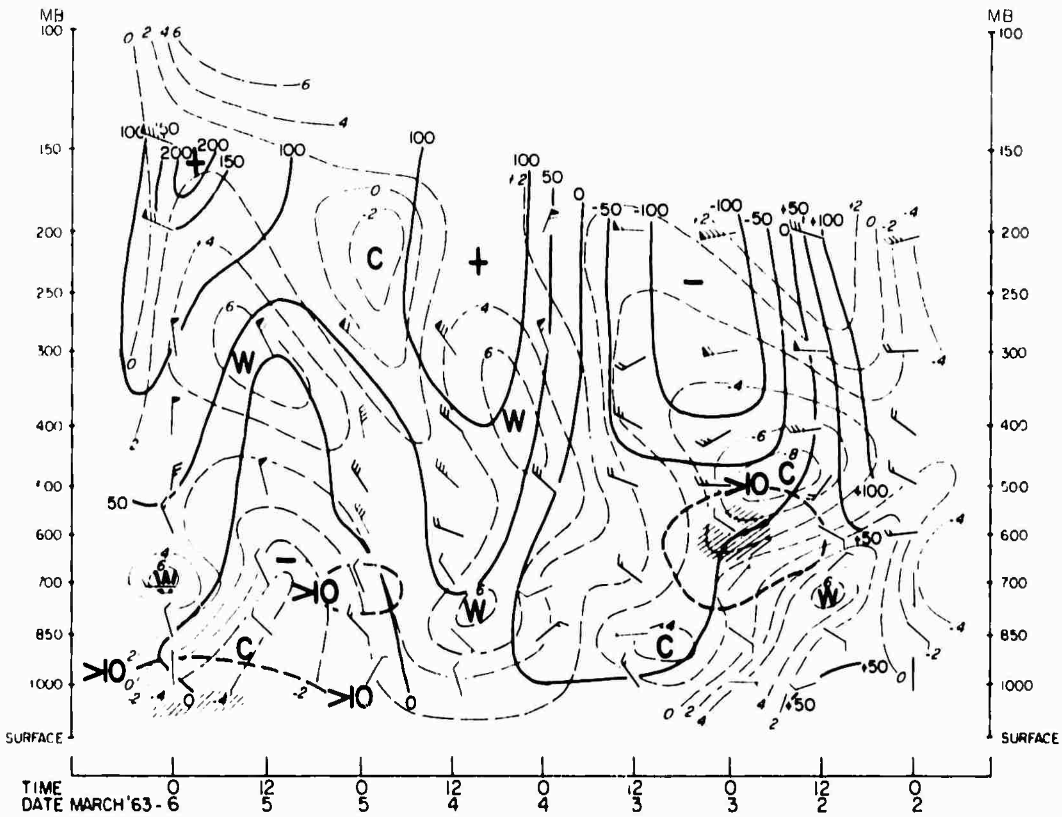


Figure 78.--Vertical time cross-section at Bombay, India, 2-6 March 1963. Heavy solid lines are 24-hour height change in meters, with the 24-hour temperature change in °C (thin dashed lines), the boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C dewpoint depression (shaded).

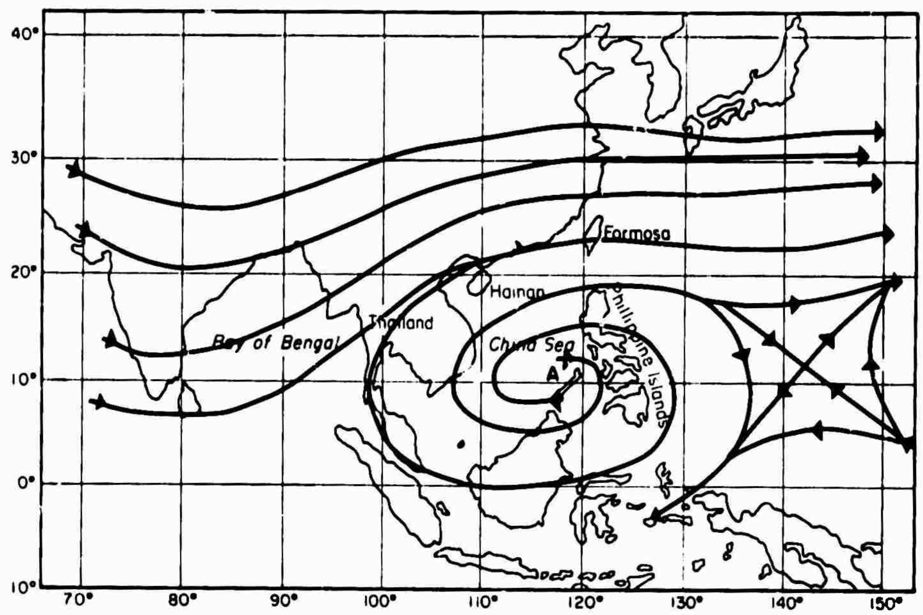


Figure 79.--300 mb. streamline analysis at 0000 GMT, 5 March 1963 (analyzed by the Thailand Meteorological Department).

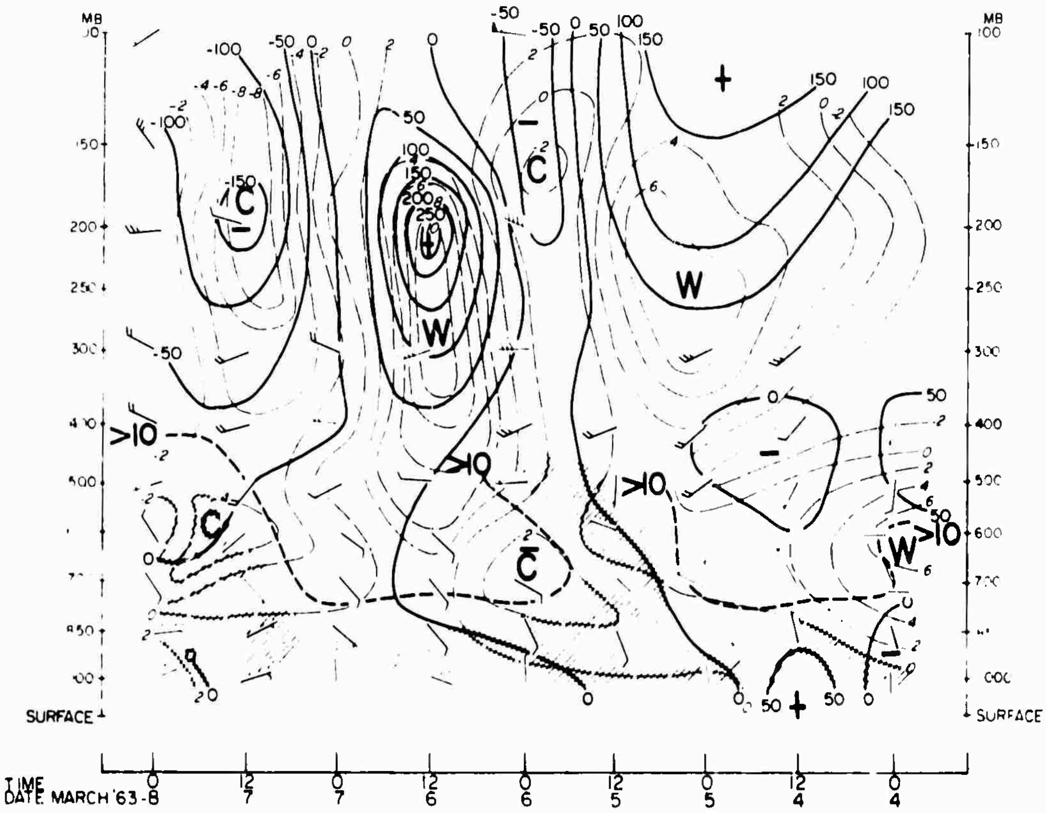


Figure 80.--Vertical time cross-section at Port Blair Andaman Is., 4-8 March 1963. Heavy solid lines are 24-hour height change in meters, with the 24-hour temperature change in °C (thin dashed lines), the boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

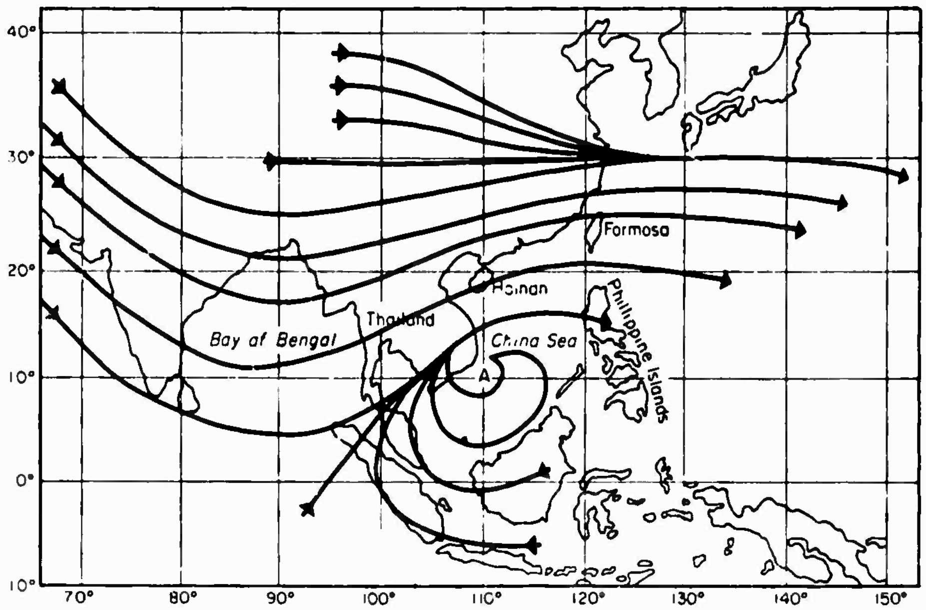


Figure 81.--300 mb. streamline analysis at 0000 GMT, 6 March 1963 (analyzed by Thailand Meteorological Department).

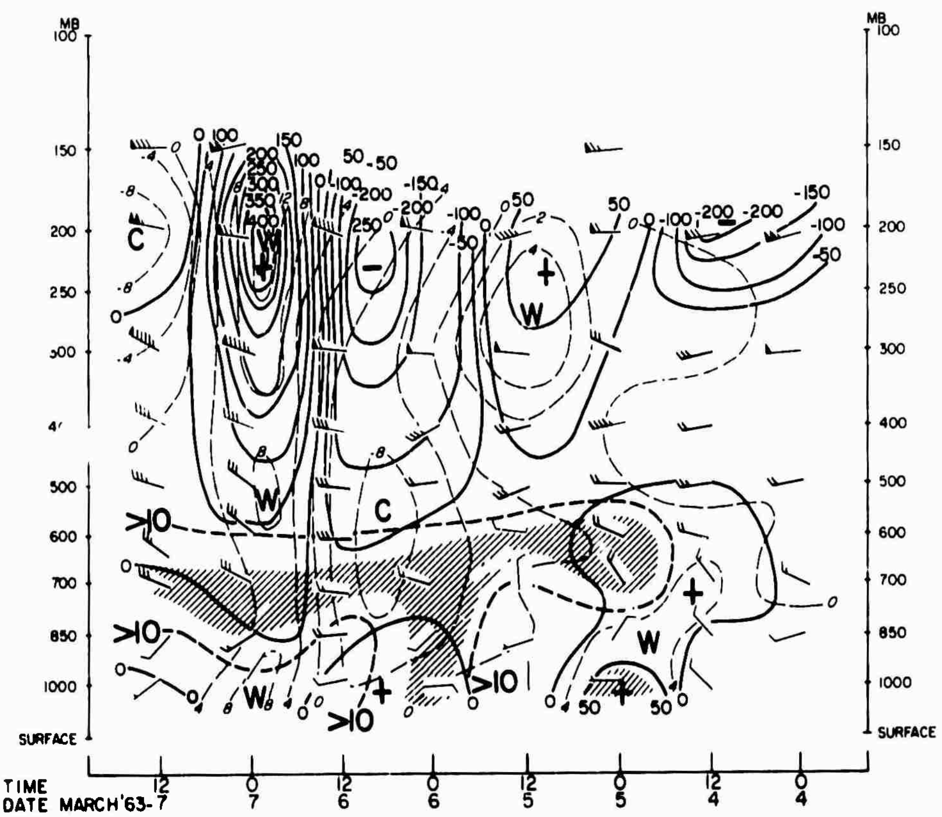


Figure 82.--Vertical time cross-section at Calcutta, India, 4-7 March 1963. Heavy solid lines are 24-hour height change in meters, with the 24-hour temperature change in °C (thin dashed lines), the boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

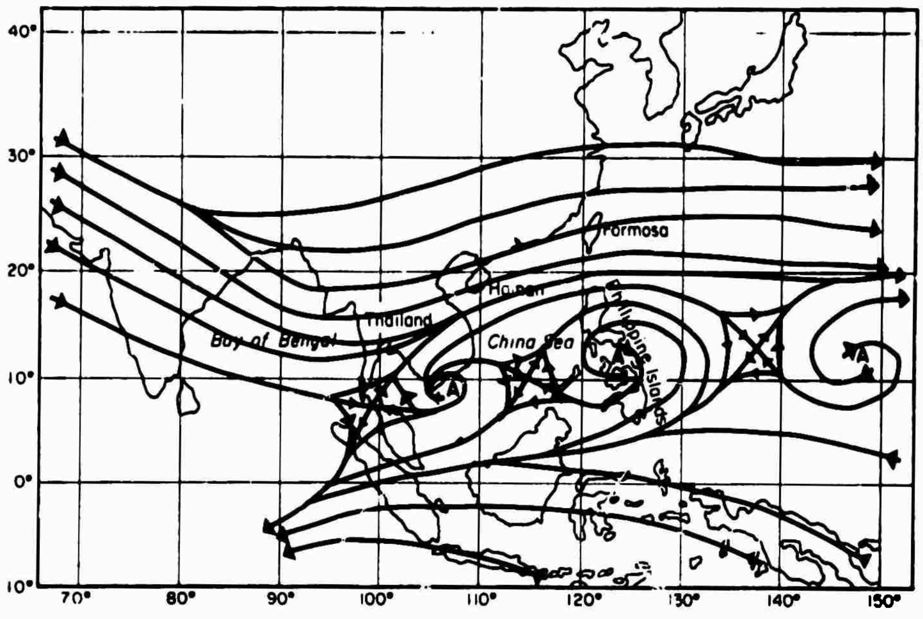


Figure 83.--300 mb. streamline analysis at 0000 GMT, 7 March 1963 (analyzed by Thailand Meteorological Department).

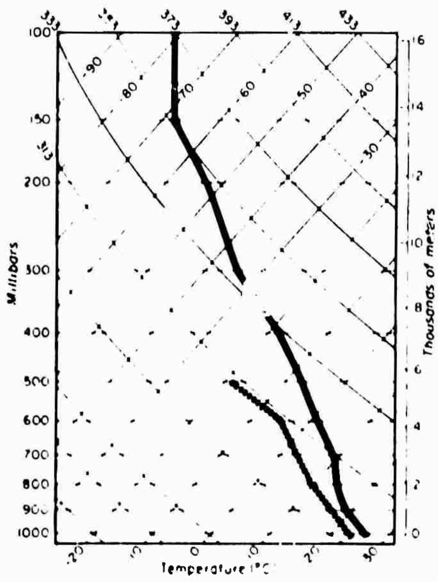


Figure 84.--Skew T, Log P Diagram for Bangkok, Thailand at 0000 GMT, 7 March 1963. Temperatures given by solid line and dewpoint by the dashed line.

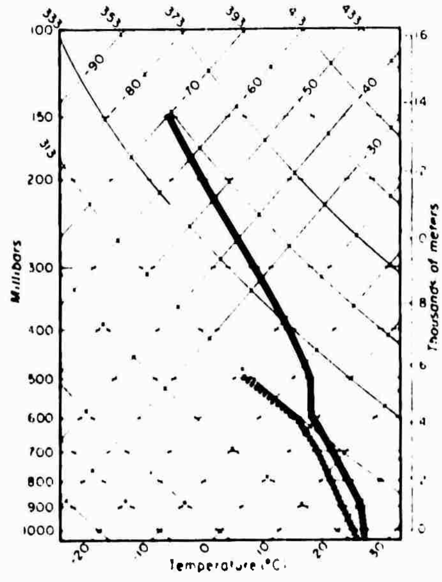


Figure 85.--Skew T, Log P Diagram for Bangkok, Thailand at 0000 GMT, 8 March 1963. Temperatures given by solid line and dewpoint by the dashed line.

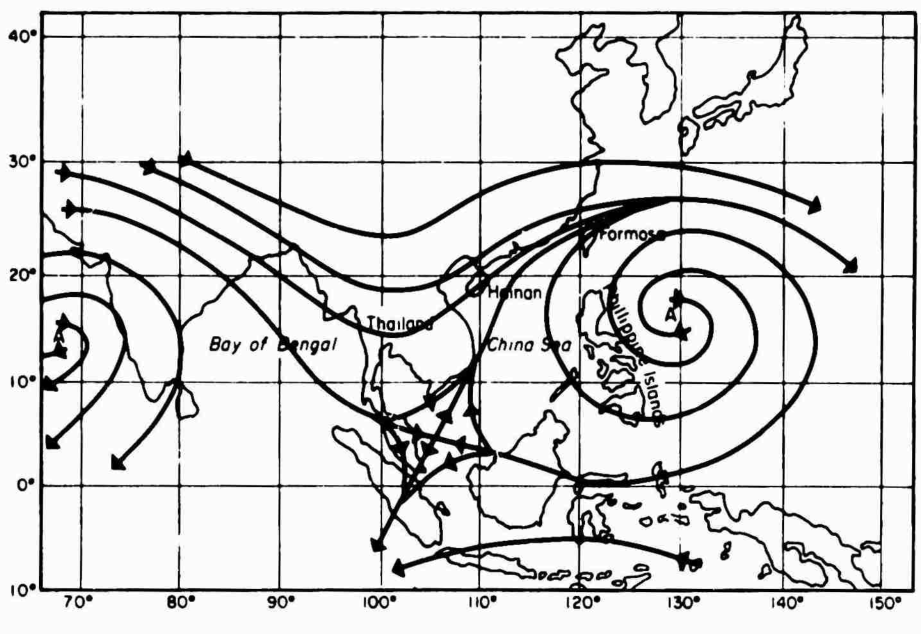


Figure 86.--300 mb. streamline analysis at 0000 GMT, 8 March 1963 (analyzed by Thailand Meteorological Department).

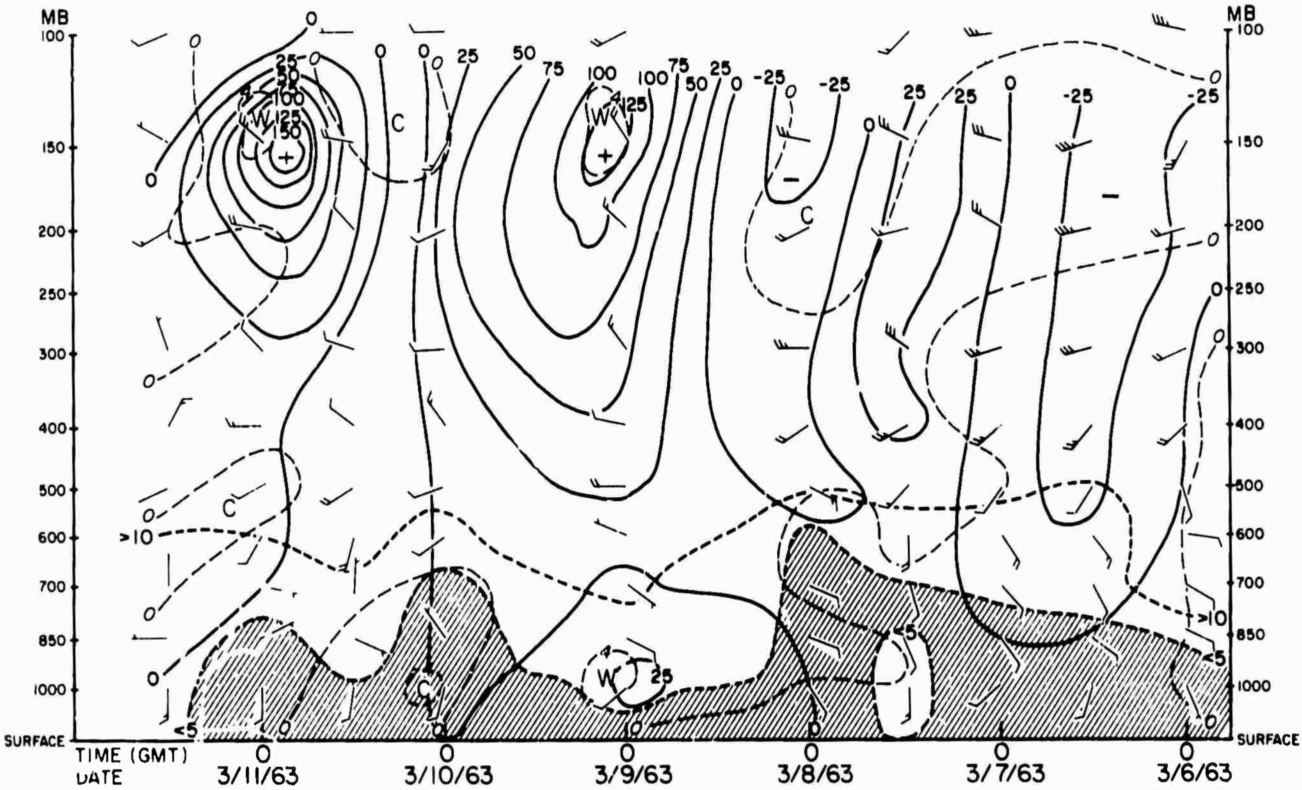


Figure 87.--Vertical time cross-section at Bangkok, Thailand, 6-11 March 1963. Heavy solid lines are 24-hour height change in meters, with the 24-hour temperature change in °C (thin dashed lines), the boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C dewpoint depression (shaded).

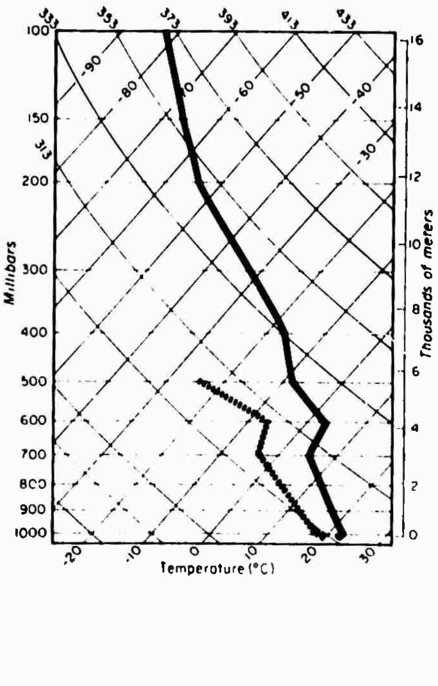


Figure 88.--Skew T, Log P Diagram for Saigon, Vietnam at 0000 GMT, 8 March 1963. Temperatures given by solid line and dewpoints by the dashed line.

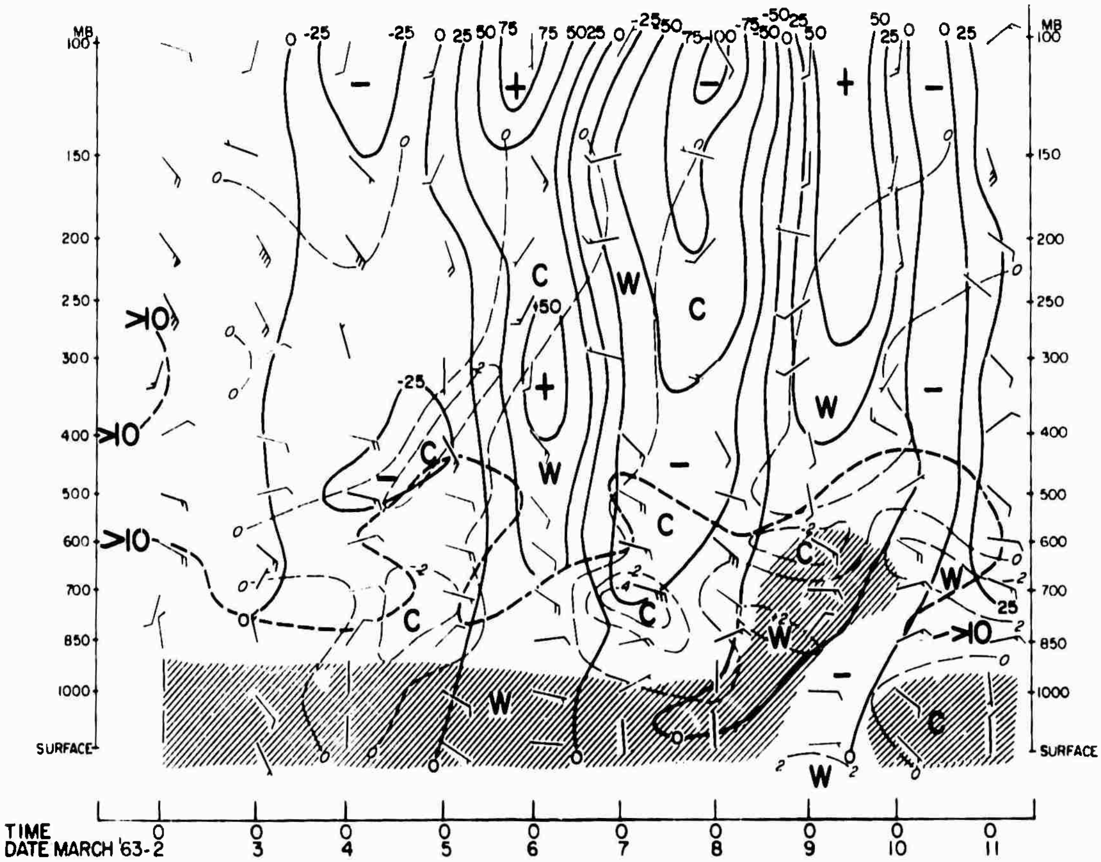
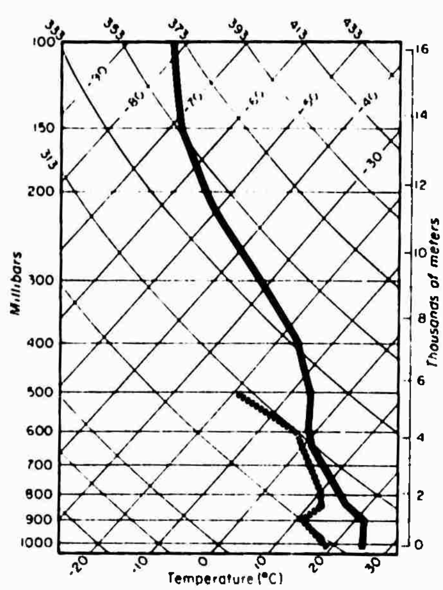


Figure 89.--Vertical time cross-section at Saigon, Vietnam, 2-11 March 1963. Heavy solid lines are 24-hour height change in meters, with the 24-hour temperature change in °C (thin dashed lines), the boundary of more than 10°C dewpoint depression (heavy dashed lines), and less than 5°C dewpoint depression (shaded).

Figure 90.--Skew T, Log P Diagram for Saigon, Vietnam at 0000 GMT, 9 March 1963. Temperatures given by solid line and dewpoints by the dashed line.



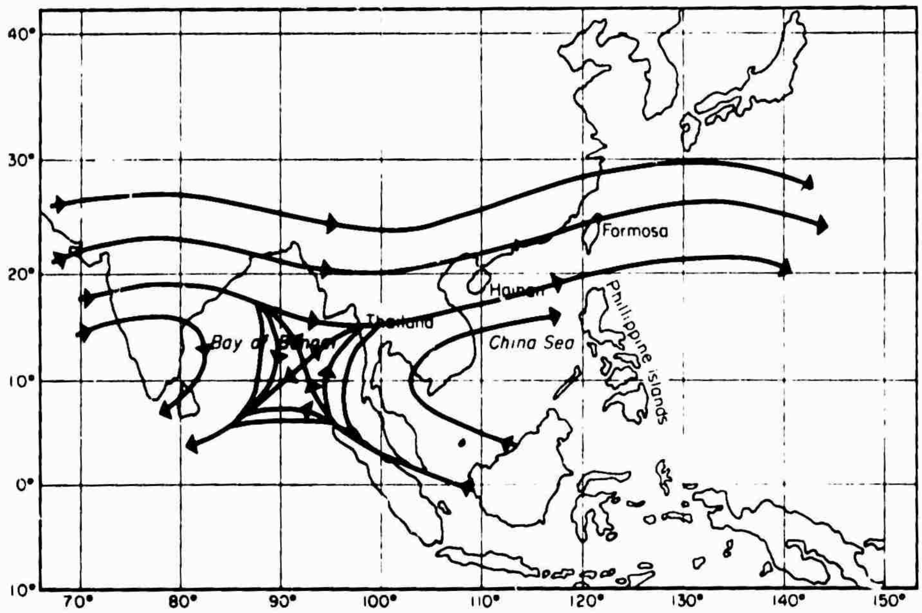


Figure 91.--300 mb. streamline analysis at 0000 GMT, 9 March 1963 (analyzed by Thailand Meteorological Department).

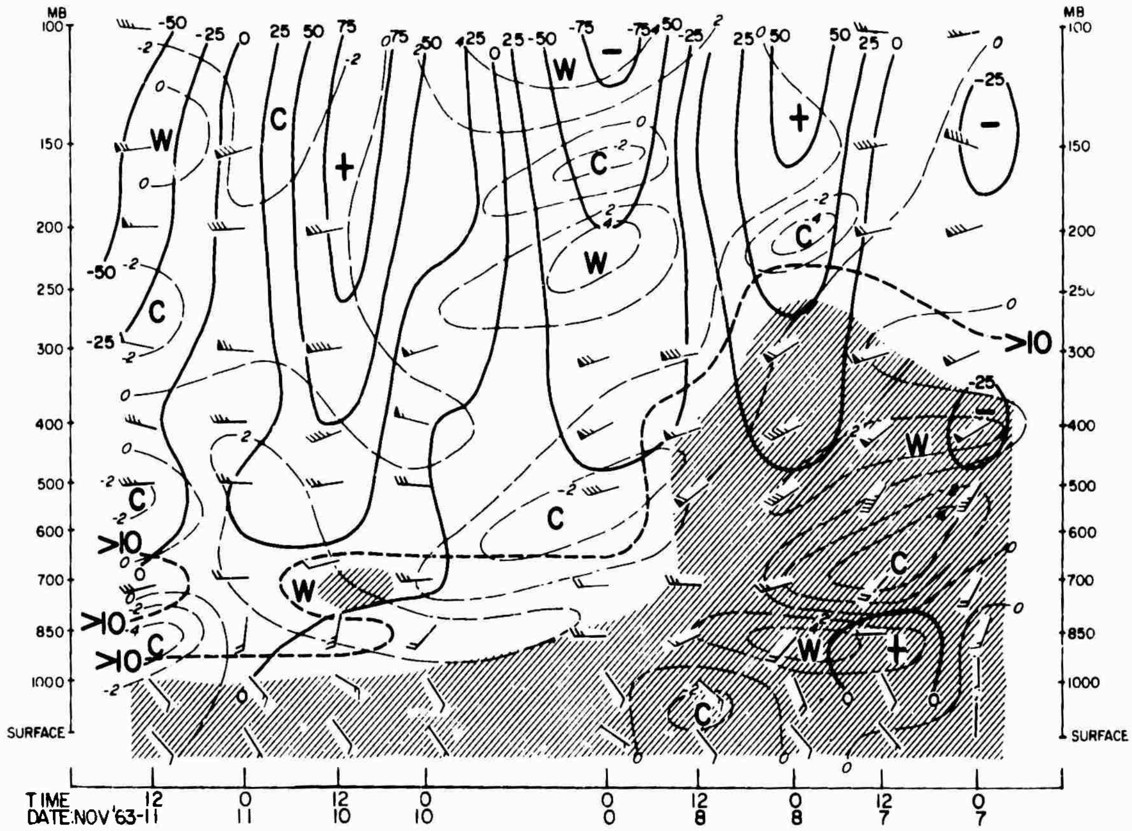


Figure 92.--Vertical time cross-section at Hanoi, North Vietnam, 7-11 March 1963. Heavy solid lines are 24-hour height change in meters, with the 24-hour temperature change in °C (thin dashed lines), the boundary of more than 10°C dewpoint depression (heavy dashed lines) and less than 5°C dewpoint depression (shaded).

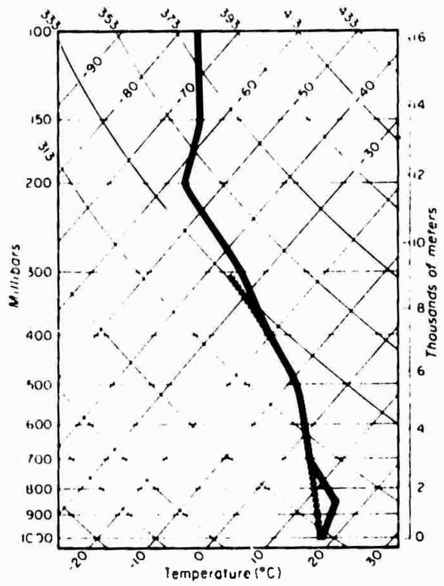


Figure 93.--Skew T, Log P Diagram for Hanoi, North Vietnam at 0000 GMT, 8 March 1963. Temperatures given by solid line and dewpoints by the dashed line.

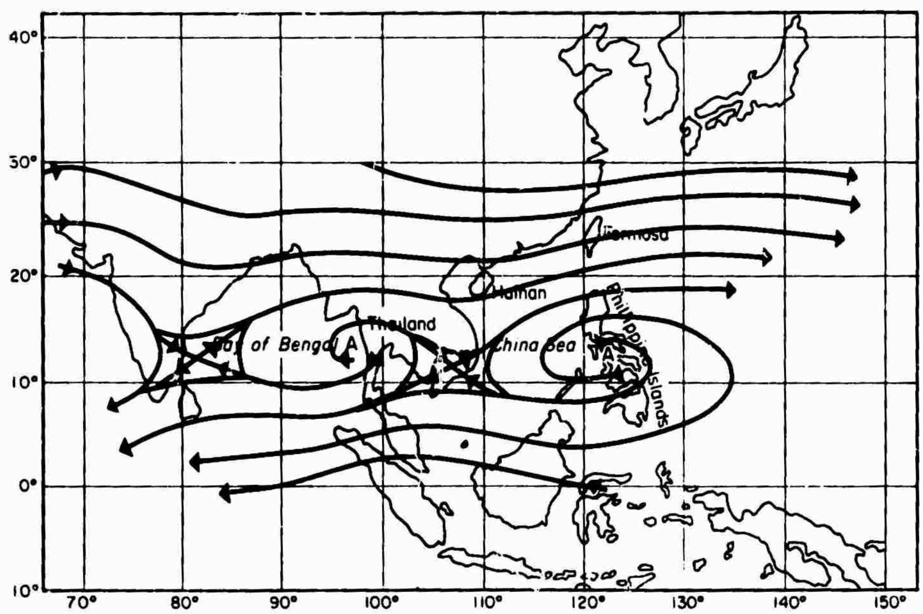


Figure 94.--300 mb. streamline analysis at 0000 GMT, 10 March 1963 (analyzed by Thailand Meteorological Department).

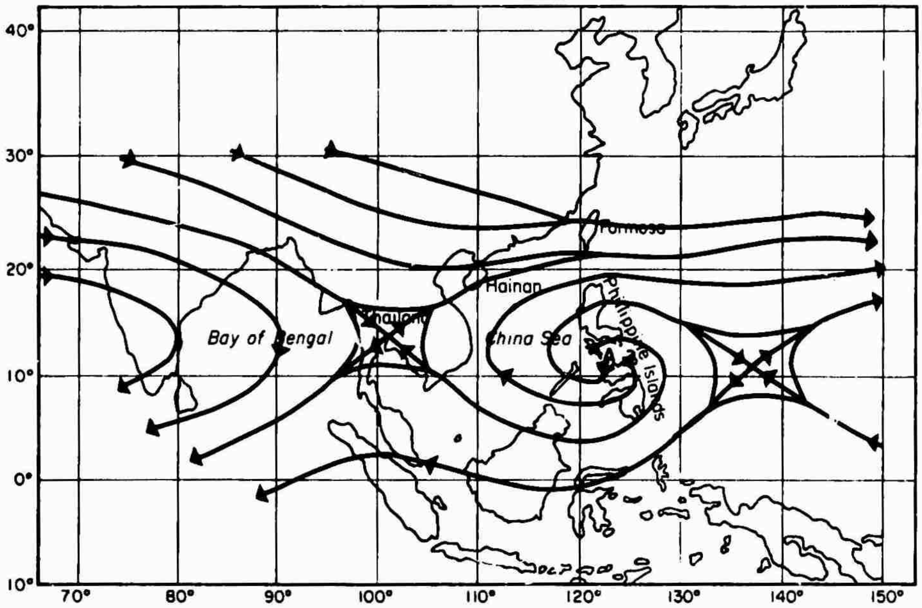


Figure 95.--300 mb. streamline analysis at 0000 GMT, 11 March 1963 (analyzed by Thailand Meteorological department).

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APPENDIXES

A. STATION LIST

The station list includes World Meteorological Organization (WMO) block and station number, name, latitude and longitude for all precipitation and cloud data and rawinsonde data stations.

NUMBER	------------- NAME -------------	-LAT- D M	-LONG- D M
41900	SYLHET PAKISTAN	24 54	91 53
96491	SANDAKAN SABAH	5 54	118 4
41940	CHITTAGONG CITY PAKISTAN	22 21	91 50
41950	COXS BAZAR PAKISTAN	21 26	91 58
42311	SIBSAGAR INDIA	26 59	94 38
42314	DIBRUGARM INDIA/MOHANBARI	27 29	95 1
96471	JESSELTON SABAH	5 57	116 3
42415	TEZPUR INDIA	26 37	92 47
42516	SHILLONG INDIA	25 34	91 53
42619	SILCHAR INDIA	24 49	92 48
42623	IMPHAL INDIA/TULIHAL	24 46	93 54
42724	AGARTALA INDIA	23 53	91 15
42727	AIJAR INDIA	23 44	92 43
96465	LABUAN SABAH	5 17	115 16
48001	PUTAO BURMA	27 20	97 25
48008	MYITKYINA BURMA	25 22	97 24
48018	KATHA BURMA	24 10	96 20
48019	BHAMO BURMA	24 16	97 12
48035	LASHIO BURMA	22 56	97 45
48042	MANDALAY BURMA	21 59	96 6
48053	MEIKTILA BURMA	20 50	95 50
48057	TAUNGGYI BURMA	20 47	97 3
48060	KENGTUNG BURMA	21 18	99 37
48062	AKYAB BURMA	20 8	92 53
48064	MINBU BURMA	20 10	94 53
48071	KYAUKPYU BURMA	19 25	93 33
48074	PYINMANA BURMA	19 43	96 13
48075	LOIKAW BURMA	19 41	97 13
48078	TOUNGOO BURMA	18 55	96 28
48080	SANDOWAY BURMA	18 28	94 21
48094	BASSEIN BURMA	16 46	94 46
48096	MINGALADON BURMA	16 54	96 11
48103	MOULMEIN BURMA	16 30	97 37
48108	TAVOY BURMA	14 6	98 13
48109	COCO ISLAND INDIAN OCEAN IS.	14 7	93 22
48110	MERGUI BURMA	12 26	98 36
48112	VICTORIA POINT BURMA	9 58	98 35
48300	MAE HONGSON THAILAND	19 18	97 50
48301	FANG THAILAND	19 55	99 13
48303	CHIANGRAI THAILAND	19 55	99 50
48310	CHIANG KHONG THAILAND	20 17	100 24
48325	MAE SARIANG THAILAND	18 10	97 50
48326	HOT THAILAND	18 6	98 36
59954	LING-SHUI HAINAN IS. CHINA	18 32	110 2
48328	LAMPANG THAILAND	18 15	99 30
48330	PHRAE THAILAND	18 10	100 8
48331	MAN THAILAND	18 47	100 47

NUMBER	NAME	-LAT- D	M	-LONG- D	M
48351	UTTARADIT THAILAND	17	37	100	8
48353	LOEI THAILAND	17	32	101	30
48354	UDON THAILAND	17	15	102	45
48355	BUNG KAN THAILAND	18	23	103	37
48356	SAKON NAKHON THAILAND	17	10	104	9
48357	NAKHON PHANOM THAILAND	17	22	104	39
48375	MAE SOT THAILAND	16	40	98	33
48376	TAK THAILAND	16	51	99	7
48378	PHITSANDLOK THAILAND	16	50	100	16
48379	PHETCHABUN THAILAND	16	25	101	8
48381	KHON KAEN THAILAND	16	20	102	51
48383	MUKDAHAN THAILAND	16	33	104	44
48400	NAKHON SAWAN THAILAND	15	48	100	10
48403	CHAIYAPHUM THAILAND	15	45	102	2
48405	ROI ET THAILAND	16	3	103	41
48407	UBON THAILAND	15	14	104	52
48425	SUPHANBURI THAILAND	14	30	100	10
48426	LOPBURI THAILAND	14	48	100	37
48430	PRACHINBURI THAILAND	14	10	101	10
48431	NAKHON RATCHASIMA THAILAND/KORAT	14	58	102	5
48432	SURIN THAILAND	14	53	103	29
48450	KANCHANABURI THAILAND	14	10	99	32
48451	PHETBURI THAILAND	13	6	99	57
59855	CHIA-CHI-SHIH HAINAN IS. CHINA	19	17	110	28
48459	CHONBURI THAILAND	13	22	100	59
48462	ARANYAPRATHET THAILAND	13	42	102	35
48475	HJA HIN THAILAND	12	34	99	48
48477	SATTAHIP THAILAND	12	39	100	53
48479	PONG NAMRON THAILAND	12	55	102	23
48480	CHANTHABURI THAILAND	12	37	102	7
48500	PRACHUAP KHIRIKHAN THAILAND	11	48	99	48
48501	KHLONG YAI THAILAND	11	47	102	53
48517	CHUMPHON THAILAND	10	27	99	15
48532	RANONG THAILAND	9	58	98	38
48548	TAKUA PA THAILAND	8	52	98	21
48551	BAN DON THAILAND	9	8	99	18
48552	NAKHON SI THAMMARAT THAILAND	8	25	99	58
48565	PHUKET THAILAND AIRPORT	8	8	98	19
48567	TRANG THAILAND	7	30	99	40
59849	CHIUNG-CHUNG HAINAN IS. CHINA	19	6	109	53
48583	NARATHIWAT THAILAND	6	26	101	50
48601	PENANG MALAYA/BAYAN LEPAS	5	18	100	16
48603	ALOR STAR MALAYA	6	12	100	25
48615	KOTA BHARU MALAYA	6	10	102	17
48619	KUALA TRENGGANU MALAYA	5	20	103	8
48802	CHAPA N VIETNAM	22	21	103	49
48803	LAO CAI N VIETNAM/LAOKAY	22	30	103	57
48808	CAO BANG N VIETNAM	22	40	106	15

NUMBER	--------------- NAME ---------------	-LAT- D	M	-LONG- D	M
48810	BAC KAN N VIETNAM	22	9	105	40
48820	HANOI N VIETNAM/GIALAM	21	3	105	52
48823	NAM DINH N VIETNAM	20	24	106	12
48826	PHU LIEN N VIETNAM	20	48	106	38
48830	LANG SON N VIETNAM	21	51	106	45
48831	THAI NGYEN N VIETNAM	21	36	105	50
48838	MONCAY N VIETNAM	21	31	107	58
48840	THANH HOA N VIETNAM	19	48	105	47
48845	VINH N VIETNAM	18	39	105	41
48846	HATINH N VIETNAM	18	21	105	54
48848	DONG HOI N VIETNAM	17	29	106	36
48851	QUANG TRI VIETNAM	16	44	107	11
48852	HUE VIETNAM/PHU-BAI	16	24	107	41
59845	NA-TA HAINAN IS. CHINA/NA-TA-SHIH	19	31	109	32
48860	HOANG SA PATTLE I PARACEL IS.	16	33	111	37
48863	QUANG-NGAI VIETNAM	15	8	108	47
48865	KONTUM VIETNAM	14	23	108	0
48866	PLEIKU VIETNAM/CU HANH APT	14	0	108	1
48870	QUI-NHON VIETNAM	13	46	109	13
48873	TUY-HOA VIETNAM	13	3	109	20
48875	BAN ME THUOT VIETNAM	12	41	108	7
48877	NHA TRANG VIETNAM	12	14	109	11
48881	DALAT VIETNAM/LIEN KHUONG	11	45	108	23
48883	DI LING VIETNAM/DJIRING	11	34	108	4
48887	PHAN-THIET VIETNAM	10	56	108	6
48896	BIEN-HOA VIETNAM	10	58	106	49
59838	PEI-LI HAINAN IS. CHINA	19	8	108	38
48903	VUNG TAU VIETNAM/CAP ST JACQUES	10	20	107	5
48907	RACH GIA VIETNAM	10	0	105	5
48913	SOC TRANG VIETNAM/CITY APT	9	35	105	57
48914	AN-XUYEN VIETNAM/CAMAU	9	10	105	10
48917	PHU-QUOC VIETNAM	10	13	103	58
48918	CON-SON VIETNAM	8	42	106	35
48920	MY THO VIETNAM	10	21	106	21
48922	CHAUDOC VIETNAM	10	42	105	6
48930	LUANG-PRABANG LAOS	19	53	102	8
48935	PLAINE DES JARRES LAOS/XIENG-KHOU	19	28	103	8
48940	VIENTIANE LAOS	17	57	102	34
48948	SENO LAOS	16	40	105	0
48955	PAKSE LAOS	15	7	105	47
48962	BATTAMBANG CAMBODIA	13	6	103	12
48966	SIEMREAP CAMBODIA/ANGKOR	13	22	103	51
48968	KRAKOR CAMBODIA	12	31	104	11
48969	KOMPONG THOM	12	42	104	54
48970	SAMBOR	12	46	105	58
48972	STUNG TRENG CAMBODIA	13	31	105	58
48974	VOEUNE SAI CAMBODIA	13	59	106	46
48976	O RAING CAMBODIA	12	22	107	19

NUMBER	--------------- NAME ---------------	-LAT-		-LONG-	
		D	M	D	M
48983	KOMPONG SOM CAMBODIA	10	38	103	29
48985	KAMPOT CAMBODIA	10	37	104	13
48986	KOMPONG SPEU	11	27	104	30
48991	PHNOM-PENH CAMBODIA/POCHENTONG	11	33	104	51
48992	TAKEO CAMBODIA	10	59	104	47
48995	KOMPONG-CHAM CAMBODIA	12	0	105	27
48997	MIMOT CAMBODIA	11	49	106	11
48998	SVAY RIENG CAMBODIA	11	5	105	48
56651	LI-CHIANG CHINA	26	57	100	18
56671	HUI-LI CHINA/HWEILI	26	50	102	15
59754	HSU-WEN CHINA	20	20	110	8
56951	LINTSANG CHINA	23	51	100	13
56954	LAN-TSANG CHINA	22	48	100	7
56959	CHING-HUNG CHINA	21	55	100	45
56964	SSU-MAO CHINA/SZEMAO	22	46	101	5
56966	YUAN-CHIANG/YUANKIANG	23	38	101	58
56985	MENG-TZU CHINA/MENGTZE	23	20	103	23
57707	PI-CHIEH CHINA	27	18	105	14
57745	CHIH-CHIANG CHINA	27	27	109	38
57799	CHI-AN CHINA	27	5	114	55
57816	KUEI-YANG CHINA	26	34	106	42
57866	LING-LING CHINA	26	22	111	31
57902	HSING-JEN CHINA	25	25	105	15
57957	KUEI-LIN CHINA	25	15	110	10
57993	KAN-HSIEN CHINA/KANCHOW	25	50	114	50
58847	FU-CHOU CHINA	26	5	119	18
58921	YUNG-AN CHINA	25	58	117	21
58931	CHIH-SHUI CHINA/DEIYUNSHIAN	25	43	118	6
59023	CHIN-CHENG	24	48	108	0
59037	TU-AN CHINA	24	1	108	5
59046	LIU-CHOU CHINA/LIUCHOW	24	18	109	16
59058	MENG-SHAN CHINA	24	13	110	32
59065	PA-PU CHINA/HO-HSIEN	24	26	111	31
59072	LIEN-HSIEN CHINA	24	44	112	25
59082	CHU-CHIANG CHINA	24	50	113	30
59087	FO-KANG CHINA	23	52	113	32
59096	LIEN-PANG CHINA	24	19	114	30
59211	PAI-SE CHINA/POSEH	23	55	106	32
59218	CHING-HSI CHINA	23	8	106	25
59224	TIEN-TUNG CHINA	23	36	107	7
59242	LAI-PIN CHINA	23	45	109	13
59254	KUEI-PING CHINA	23	23	110	3
59265	WUCHOW CHINA/TSANG-WU	23	30	111	25
59271	KUANG-NING CHINA	23	38	112	26
59278	KAO-YAO CHINA	23	3	112	27
59287	KUANG-CHOU CHINA/CANTON	23	10	113	20
59293	HO-YUAN CHINA	23	45	114	50
59298	HUI-YANG CHINA/WAICHOW	23	5	114	25

NUMBER	-------------- NAME --------------	-LAT- D	M	-LONG- D	M
59321	TUNG-SHAN CHINA	23	48	117	33
59417	LUNG-CHING CHINA	22	22	106	45
59431	NANNING CHINA/YUNGNING	22	51	108	19
59446	LING-SHAN CHINA	22	25	109	17
59453	YU-LIN-HSIN CHINA/WATLAM	22	38	110	8
59456	TUNG-CHEN CHINA/HSIENYLH	22	22	110	56
59478	TAI-SHAN CHINA/SUNNING	22	16	112	46
59493	PAO-AN CHINA	22	40	114	7
59501	SHAN-WEI CHINA	22	46	115	22
59632	CHIN-HSIEN CHINA/CHIN CHOW	21	57	108	36
59644	PEI-HAI CHINA	21	29	109	6
59647	WEI-CHOU-TAO CHINA/WEICHOW IS.	21	3	109	8
59658	CHAN-CHIANG CHINA/FT BAYARD	21	2	110	28
59663	YANG-CHIANG CHINA	21	54	111	57
59664	TIEN-PAI CHINA/TIENPAK	21	30	111	18
56778	KUN-MING CHINA	25	2	102	43
59758	HAI-KOW HAINAN IS. CHINA	20	0	110	25
48900	SAIGON VIETNAM/TAN SON NHUT APT	10	49	106	39
48855	DA NANG VIETNAM	16	2	108	12
48568	SONGKHLA THAILAND	7	11	100	37
48455	BANGKOK THAILAND	13	44	100	30
48327	CHIANGMAI THAILAND	18	47	98	59
43333	PORT BLAIR ANDAMAN IS.	11	40	92	43
42410	GAUHATI INDIA	26	5	91	43
41917	DACCA PAKISTAN/TEJGAON	23	46	90	23
45004	KINGS PARK HONG KONG	22	19	114	11
40309	KOROR ISLAND PALAU IS WB	7	20	134	29
41207	ANGELES LUZON PI/ CLARK AB	15	11	120	33
41415	GUAM MARIANAS ISLANDS	13	28	144	47
42204	OKINAWA RYUKYU IS/KADENA AB	26	20	127	46
40597	ADEN ARABIA/KHORMAKSAR	12	50	45	1
40427	BAHRAIN IS U K /MUHARRAQ	26	16	50	37
41350	GAN ISLAND MALDIVE IS	0	-41	73	9
42339	JODHPUR INDIA	26	15	73	3
42475	ALLAHABAD INDIA/BAMHRAULI	25	26	81	43
42809	CALCUTTA INDIA/DUM DUM	22	39	88	26
42867	NAGPUR INDIA/SONEGAON	21	5	79	2
43003	BOMBAY INDIA/SANTACRUZ AERODROME	19	6	72	51
43149	VISHAKHAPATNAM INDIA	17	43	83	13
43279	MARRAS INDIA/MINAMBAKKAM	12	59	80	10
43295	BANGALORE INDIA	12	57	77	40
43371	TRIVANDRUM INDIA	8	29	76	54
48694	SINGAPORE AIRPORT SINGAPORE	1	21	103	54
96745	DJAKARTA JAVA/ OBSERVATORY	-6	-9	106	50
48097	RANGOON BURMA	16	46	96	10
48819	HANOI N VIETNAM	21	1	105	51

B COMPUTER PROGRAMS

The routines used in this report are listed here and are followed by the type of IBM computer system on which they were run.

PROGRAM PRCPTP-Wrote binary precipitation and cloud data tape from BCD raw data tape (7040).
PROGRAM PKTRAW-Wrote two sets of three binary rawinsonde tapes each; one set in synoptic order, the other in station order, from original ETAC-supplied BCD tapes (7040).
PROGRAM PRCPLT-Plots precipitation and cloud amount on Southeast Asia map (360/50).
PROGRAM CRSPLT-Plots vertical time cross-section from rawinsonde station order tape (360/50).
PROGRAM LL$PLT-Plots vertical space cross-section from rawinsonde synoptic order tapes (360/50).
PROGRAM SKWPLT-Plots Skew T, Log P Diagram from rawinsonde station order tape (360/50).
PROGRAM ERLPLT-Plots surface and constant pressure maps from rawinsonde synoptic order tapes (360/50).
SUBROUTINE RMDPLT-Plots WBAN-type station model (360/50).
SUBROUTINE BRBPLT-Plots WBAN-type wind-flag with barbs and pennants to display wind direction and speed in a single symbol to nearest five units (360/50).
INTEGER FUNCTION SEQNO-Routine provides a unique sequence number from a year-month-day combination (360/50).
DICTIONARY/STADIC/-Station-number dictionary for all stations (360/50).
DICTIONARY/NAMDIC/-Station-name dictionary for all rawinsonde data stations (360/50).
DICTIONARY/POSDIC/-Station-position dictionary for all stations (360/50).

These computer programs are available on request to:

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